NOT

OF

PROFESSOR TYND

ON

ICE, WATER, VAPOUR, AND AIR.

HANDBOOK

OF

ICE AND GLACIERS.

NOTES

OF

A COURSE OF SIX LECTURES

(Adapted to a Juvenile Auditory),

ON

ICE, WATER, VAPOUR, AND AIR.

BY

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In preparing these Notes, which I have tried to render clear and compact, I have not forgotten that you are growing older and wiser: otherwise I might have made them even shorter and simpler than they are.

Probably but few of you, and these the very youngest, will find the notes either long or difficult; but even in their case all difficulty will soon disappear.

Doubtless many of you when you become full-grown men, and not I trust before, will try your strength upon the mountains. I hope, when there, that you will never confound courage with recklessness, or forget that on the Alps bravery and caution ought always to be combined.

JOHN TYNDALL.

CHRISTMAS, 1871.

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NOTES

OF

A COURSE OF SIX LECTURES

ON

ICE, WATER, VAPOUR, AND AIR.

DELIVERED ON DECEMBER 28, 30, 1871; JANUARY 2, 4, 6, 9, 1872.

§ 1.

Clouds, Rains, and Rivers.

1. Every occurrence in Nature is preceded by other occurrences which are its causes, and succeeded by others which are its effects. The human mind is not satisfied with observing and studying any natural occurrence alone, but takes pleasure in connecting every natural fact with what has gone before it, and with what is to come after it.

2. Thus, when we enter upon the study of rivers and glaciers our interest will be greatly augmented by taking into account not only their actual appearances, but also their causes and effects.

3. Let us trace a river to its source. Beginning where it empties itself into the sea, and following it backwards, we find it from time to time joined by tributaries which swell its waters. The river of course becomes smaller as these tributaries are passed. It shrinks first to a brook, then to a stream; this again divides itself into a number of smaller streamlets, ending in mere threads of water. These constitute the source of the river, and are usually found among hills.

4. Thus the Severn has its source in the Welsh mountains; the Thames in the Cotswold Hills; the Danube in the hills of the Black Forest; while the Rhine and the Rhone have their sources in the Alps.

5. But it is quite plain that we have not yet reached the real beginning of the river. Whence do the hill streams derive their

water? A brief residence among the mountains would prove to you that they are fed by rains. In dry weather you would find the streams feeble, sometimes indeed quite dried up. In wet weather you would see them foaming torrents. In general these streams lose themselves as little threads of water upon the hill sides; but sometimes you may trace a river to a definite spring. The river Albula in Switzerland, for instance, rushes at its origin in considerable volume from a mountain side. But you very soon assure yourself that such springs are also fed by rain, which has percolated through the rocks or soil, and which, through some orifice that it has found or formed, comes to the light of day.

6. But we cannot end here. Whence comes the rain which forms the mountain streams? Observation enables you to answer the question. Rain does not come from a clear sky. It comes from clouds. But what are clouds? Is there nothing you are acquainted with which they resemble? You discover at once a likeness between them and the condensed steam of a locomotive. At every puff of the engine a cloud is projected into the air. Watch the cloud sharply: you notice that it first forms at a little distance from the top of the funnel. Give close attention and you will sometimes see a perfectly clear space between the funnel and the cloud. Through that clear space the thing which makes the cloud must pass. What, then, is this thing which at one moment is transparent and invisible, and at the next moment visible as a dense opaque cloud?

7. It is the *steam* or *vapour of water* from the boiler. Within the boiler this steam is transparent and invisible; but to keep it in this invisible state a heat would be required as great as that within the boiler. When the vapour mingles with the cold air above the hot funnel it ceases to be vapour. Every bit of steam shrinks, when chilled, to a much more minute particle of water. The liquid particles thus produced form a kind of *water-dust* of exceeding fineness, which floats in the air, and is called *a cloud.*

8. Watch the cloud-banner from the funnel of a running locomotive; you see it growing gradually less dense. It finally melts away altogether, and if you continue your observations you will not fail to notice that the speed of its disappearance depends upon the character of the day. In humid weather the cloud hangs long and lazily in the air; in dry weather it is rapidly licked up. What has become of it? It has been reconverted into true invisible vapour.

9. The *drier* the air, and the *hotter* the air, the greater is the amount of cloud which can be thus dissolved in it. When the cloud first forms, its quantity is far greater than the air is able to maintain in an invisible state. But as the cloud mixes gradually with a larger mass of air it is more and more dissolved, and finally passes altogether from the condition of a finely-divided liquid into that of transparent vapour or gas.

10. Even on the driest day this vapour is never absent from our atmosphere. I will condense the vapour diffused through the air of our lecture-room, and freeze it to hoar-frost in your presence.

11. To produce the cloud, in the case of the locomotive, *heat* is necessary. By heating the water we first convert it into steam, and then by chilling the steam we convert it into cloud. Is there any fire in nature which produces the clouds of our atmosphere? There is: the fire of the sun.

12. Thus, by tracing backward, without any break in the chain of occurrences, our river from its end to its real beginnings, we come at length to the sun.

§ 2.

13. There are, however, rivers which have sources somewhat different from those just mentioned. They do not begin by driblets on a hill side, nor can they be traced to a spring. Go, for example, to the mouth of the river Rhone, and trace it backwards to Lyons, where it turns to the east. Bending round by Chambery you come at length to the Lake of Geneva, from which the river rushes, and which you might be disposed to regard as the source of the Rhone. But go to the head of the lake, and you find that the Rhone there enters it, that the lake is in fact a kind of expansion of the river. Follow this upwards; you find it joined by smaller rivers from the mountains right and left. Pass these, and push your journey higher still. You come at length to a huge mass of ice—the end of a glacier—which fills the Rhone valley, and from the bottom of the glacier the river rushes. In the glacier of the Rhone you thus find the source of the river Rhone.

14. But again we have not reached the real beginning of the river. You soon convince yourself that this earliest water of the Rhone is produced by the melting of the ice. You get upon the glacier and walk upwards along it. After a time the ice disappears and you come upon snow. If you are a competent mountaineer you may go to the very top of this great snow-field, and if you cross the top and descend at the other side you finally quit the snow, and get upon another glacier called the Trift, from the end of which rushes a river smaller than the Rhone.

15. You soon learn that the mountain snow feeds the glacier. By some means or other the snow is converted into ice. But whence comes the snow? Like the rain, it comes from the clouds, which, as before, can be traced to vapour raised by the sun. Without solar fire we could have no atmospheric vapour, without vapour no clouds, without clouds no snow, and without snow no glaciers. Curious then as the conclusion may be, the cold ice of the Alps has its origin in the heat of the sun.

§ 3.

The Waves of Light.

16. But what is the sun? We know its size and its weight. We also know that it is a globe of fire far hotter than any fire upon earth. But we now enter upon another inquiry. We have to learn definitely what is the meaning of solar light and solar heat; in what way they make themselves known to our senses; by what means they get from the sun to the earth, and how, when there, they produce the clouds of our atmosphere, and thus originate our rivers and our glaciers.

17. If in a dark room you close your eyes and press the eyelid with your finger-nail, a circle of light will be seen opposite to the point pressed, while a sharp blow upon the eye produces the impression of a flash of light. There is a nerve specially devoted to the purposes of vision which comes from the brain to the back of the eye, and there divides into fine filaments, which are woven together to a kind of screen called the *retina.* The retina can be excited in various ways so as to produce the consciousness of light; it may, as we have seen, be excited by the rude mechanical action of a blow imparted to the eye.

18. Can the impression of real light be due to any action of this kind? In some way or other luminous bodies have the power of affecting the retina—but *how?*

19. It was long supposed that from such bodies issued with inconceivable rapidity, an inconceivably fine matter, which flew through space, passed through the pores supposed to exist in the humours of the eye, reached the retina behind, and by their shock against the retina, aroused the sensation of light.

20. This theory, which was supported by the greatest men, among others by Sir Isaac Newton, was found competent to explain a great number of the phenomena of light, but it was not found competent to explain *all* the phenomena. As the skill and knowledge of experimenters increased, large classes of facts were revealed which could only be explained by assuming that light was produced, not by a fine matter flying through space and hitting the retina, but by the shock of minute waves against the retina.

21. Dip your finger into a basin of water, and cause it to quiver rapidly to and fro. From the point of disturbance issue small ripples which are carried forward by the water, and which finally strike the basin. Here, in the vibrating finger, you have a source of agitation; in the water you have a vehicle through which the finger's motion is transmitted, and you have finally the side of the basin which receives the shock of the little waves.

22. In like manner, according to the *wave theory* of light, you have a source of agitation in the vibrating atoms, or smallest particles, of the luminous body; you have a vehicle of transmission in a sub-

stance which is supposed to fill all space, and to be diffused through the humours of the eye; and finally, you have the retina, which receives the successive shocks of the waves. These shocks are supposed to produce the sensation of light.

23. We are here dealing, for the most part, with suppositions and assumptions merely. We have never seen the atoms of a luminous body, nor their motions. We have never seen the medium which transmits their motions, nor the waves of that medium. How, then, do we come to assume their existence?

24. Before such an idea could have taken any real root in the human mind, it must have been well disciplined and prepared by observations and calculations of ordinary wave-motion. It was necessary to know how both water-waves and sound-waves are formed and propagated. It was above all things necessary to know how waves, passing through the same medium, act upon each other. Thus disciplined, the mind was prepared to detect any resemblance presenting itself between the action of light and that of waves. Great classes of optical phenomena accordingly appeared which could be accounted for in the most complete and satisfactory manner by assuming them to be produced by waves, and which could not be otherwise accounted for. It is because of its competence to explain all the phenomena of light that the wave theory now receives universal acceptance on the part of scientific men.

25. Let me use an illustration. We infer from the flint implements recently found in such profusion all over England and in other countries, that they were produced by men, because, as far as our experience goes, nothing but man could form such implements. In like manner, we infer from the phenomena of light the agency of waves, because, as far as our experience goes, no other agency could produce the phenomena.

§ 4.

The Waves of Darkness which produce the Vapour of our Atmosphere and melt our Glaciers.

26. Thus, in a general way, I have given you the conception and the grounds of the conception, which regards light as the product of wave-motion; but we must go farther than this, and follow the conception into some of its details. We have all seen the waves of water, and we know that there are waves of different sizes,—different in length and different in height. When, therefore, you are told that the atoms of the sun, and of almost all other luminous bodies, vibrate at different rates, and produce waves of different sizes, your experience of water-waves will enable you to form a tolerably clear notion of what is meant.

27. As observed above we have never seen the light-waves, but we judge of their presence, their position, and their magnitude, by

their effects. Their lengths have been thus determined and found to vary from about $\frac{1}{30000}$th to $\frac{1}{60000}$th of an inch.

28. But besides the waves which produce light, the sun sends forth incessantly a multitude of waves which produce no light. The largest waves which the sun sends forth are of this non-luminous character. These large waves possess the highest heating power.

29. A common sunbeam contains waves of all kinds, but it is possible to *sift* or *filter* the beam so as to intercept all its light-yielding waves, and at the same time to allow its purely heat-yielding waves to pass unimpeded. For substances have been discovered which, while intensely opaque to the light-waves, are almost perfectly transparent to the others. On the other hand, it is possible, by the choice of proper substances, to intercept in a great degree the pure heat-waves, and to allow the pure light-waves free transmission. This last separation is, however, not so perfect as the first.

30. I will show you how the one class of waves may be detached from the other class, and that waves competent to light a fire, fuse metal, or burn the hand like a hot solid, may exist in a perfectly dark place.

31. Supposing, then, that we withdraw in the first instance the large heat-waves, and allow the light-waves alone to pass. These may be concentrated by suitable lenses and sent through water without sensibly warming it. Let the light-waves now be withdrawn, and the larger heat-waves concentrated in the same manner; they may be caused to boil the water almost instantaneously.

32. This is the point to which I wished to lead you, and which without due preparation could not be understood. You now perceive the important part played by these large darkness-waves, if I may use the term, in the work of evaporation. When they plunge into seas, lakes, and rivers, they are intercepted close to the surface, and they heat the water at the surface, thus causing it to evaporate; the light-waves at the same time entering to great depths without sensibly heating the water through which they pass. Not only, therefore, is it the sun's fire which produces evaporation, but a particular constituent of that fire, the existence of which you probably were not aware of.

33. Further, it is these self-same lightless waves which, falling upon the glaciers of the Alps, melt the ice and produce all the rivers flowing from the glaciers; for I shall prove to you that the light-waves, even when concentrated to the uttermost, are hardly able to melt the most delicate hoar-frost; much less would they be able to produce the copious liquefaction observed upon the glaciers.

34. We have here an example of the manner in which phenomena, apparently remote, are connected together in this wonderful system of things that we call Nature. You cannot study a snow-flake profoundly without being led by it to the constitution of the sun. It is thus throughout Nature. All its parts are interdependent, and the study of any one part *completely* would really involve the study of all.

§ 5.

Oceanic Distillation.

35. But we must now be more precise. The sun you know is never exactly overhead in England. But at the equator, and within certain limits north and south of it, the sun at certain periods of the year is directly overhead at noon. These limits are called the tropics of Cancer and of Capricorn. Upon the belt comprised between these two circles the sun's rays fall with their mightiest power; for here they shoot directly downwards, and heat both earth and sea more than when they strike slantingly.

36. When the vertical sunbeams strike the land they heat it, and the air in contact with the hot soil becomes heated in turn. When heated the air expands, and when it expands it becomes lighter. This lighter air rises, like wood plunged into water, through the heavier air overhead.

37. When the sunbeams fall upon the sea the water is warmed, though not so much as the land. The warmed water expands, becomes thereby lighter, and therefore continues to float upon the top. This upper layer of water warms to some extent the air in contact with it, but it also sends up a quantity of aqueous vapour, which being far lighter than air, helps the latter to rise. Thus both from the land and from the sea we have ascending currents established by the action of the sun.

38. When they reach a certain elevation in the atmosphere, these currents divide and flow, part towards the north and part towards the south; while from the north and the south a flow of heavier and colder air sets in to supply the place of the ascending warm air.

39. Incessant circulation is thus established in the atmosphere. The equatorial air and vapour flow above towards the north and south poles, while the polar air flows below towards the equator. The two currents of air thus established are called the upper and the lower trade winds.

40. But before the air returns from the poles great changes have occurred. For the air as it quitted the equatorial regions was laden with aqueous vapour, which could not subsist in the cold polar regions. It is there precipitated, falling sometimes as rain, or more commonly as snow. The land near the pole is covered with this snow, which gives birth to vast glaciers in a manner hereafter to be explained.

41. It is necessary that you should have a perfectly clear view of this process, for great mistakes have been made regarding the manner in which glaciers are related to the heat of the sun.

42. It was supposed that if the sun's heat were diminished greater glaciers than those now existing would be produced. But the lessening of the sun's heat would infallibly diminish the quantity of aqueous

vapour, and thus cut off the glaciers at their source. A brief illustration will complete your knowledge here.

43. In the process of ordinary distillation, the liquid to be distilled is heated and converted into vapour in one vessel, and chilled and reconverted into liquid in another. What has just been stated renders it plain that the earth and its atmosphere constitute a vast distilling apparatus in which the equatorial ocean plays the part of the boiler, and the chill regions of the poles the part of the condenser. In this process of distillation *heat* plays quite as necessary a part as *cold*, and before Bishop Heber could speak of "Greenland's icy mountains," the equatorial ocean had to be warmed by the sun. We shall have more to say upon this question afterwards.

§ 6.

Tropical Rains.

44. But long before the air and vapour from the equator reach the poles, precipitation occurs. Wherever a humid warm wind mixes with a cold dry one rain falls. Indeed the heaviest rains occur at those places where the sun is vertically overhead. We must inquire a little more closely into their origin.

45. Fill a bladder about two-thirds full of air at the sea level, and take it to the summit of Mont Blanc. As you ascend, the bladder becomes more and more distended; at the top of the mountain it is fully distended, and has evidently to bear a pressure from within. Returning to the sea level you find the tightness disappear, the bladder finally appearing as flaccid as at first.

46. The reason is plain. At the sea level the air within the bladder has to bear the pressure of the whole atmosphere, being thereby squeezed into a comparatively small volume. In ascending the mountain, you leave more and more of the atmosphere behind; the pressure becomes less and less, and by its expansive force the air within the bladder swells as the outside pressure is diminished. At the top of the mountain the expansion is quite sufficient to render the bladder tight, the pressure within being then actually greater than the pressure without. By means of an air-pump I will show you the expansion of a balloon partly filled with air, when the external pressure has been in part removed.

47. But why do I dwell upon this? Simply to make plain to you that the *unconfined air*, heated at the earth's surface, and ascending by its lightness, must expand more and more the higher it rises in the atmosphere.

48. And now I have to introduce to you a new fact, towards the statement of which I have been working for some time. It is this:—*The ascending air is chilled by its expansion.* Indeed this chilling is one source of the coldness of the higher atmospheric regions.

And now fix your eye upon those mixed currents of air and aqueous vapour which rise from the warm tropical ocean. They start with plenty of heat to preserve the vapour as vapour; but as they rise they come into regions already chilled, and they are still further chilled by their own expansion. The consequence might be foreseen. The load of vapour is in great part precipitated, dense clouds are formed, their particles coalesce to rain-drops, which descend daily in gushes so profuse that the word "torrential" is used to express the copiousness of the rainfall. I will show you this chilling by expansion, and also the consequent precipitation of clouds.

49. Thus long before the air from the equator reaches the poles its vapour is in great part removed from it, having redescended to the earth as rain. Still a good quantity of the vapour is carried forward which yields hail, rain, and snow in northern and southern lands.

§ 7.

Mountain Condensers.

50. To complete our view of the process of atmospheric precipitation we must take into account the action of mountains. Imagine a south-west wind blowing across the Atlantic towards Ireland. In its passage it charges itself with aqueous vapour. In the south of Ireland it encounters the mountains of Kerry: the highest of these is Magillicuddy's Reeks, near Killarney. Now the lowest stratum of this Atlantic wind is that which is most fully charged with vapour. When it encounters the base of the Kerry mountains it is tilted up and flows bodily over them. Its load of vapour is therefore carried to a height, it expands on reaching the height, it is chilled in consequence of the expansion, and comes down in copious showers of rain. From this, in fact, arises the luxuriant vegetation of the Killarney lakes; to this, indeed, they owe their water supply. The cold crests of the mountains also aid in the work of condensation.

51. Note the consequence. There is a town called Cahirciveen to the south-west of Magillicuddy's Reeks, at which observations of the rainfall have been made, and a good distance farther to the north-east, right in the course of the south-west wind, there is another town, called Portarlington, at which observations of rainfall have also been made. But before the wind reaches the latter station it has passed over the mountains of Kerry and left a great portion of its moisture behind it. What is the result? At Cahirciveen the rainfall amounts to 59 inches in a year, while at Portarlington it is only 21 inches.

52. Again, you may sometimes descend from the Alps when the fall of rain and snow is heavy and incessant, into Italy, and find the sky over the plains of Lombardy blue and cloudless, the wind at the same time *blowing over the plain towards the Alps.* Below the wind is hot enough to keep its vapour in a perfectly transparent state; but

it meets the mountains, is tilted up, expanded, and chilled. The cold of the higher summits also helps the chill. The consequence is that the vapour is precipitated as rain or snow, thus producing bad weather upon the heights, while the plains below, flooded with the same air, enjoy the aspect of the unclouded summer sun. Clouds blowing *from* the Alps are also sometimes dissolved over the plains of Lombardy.

53. In connection with the formation of clouds by mountains, one particularly instructive effect may be here noticed. You frequently see a streamer of cloud many hundred yards in length drawn out from an Alpine peak. Its steadiness appears perfect, though a strong wind may be blowing at the same time over the mountain head. Why is the cloud not blown away? It *is* blown away; its permanence is only apparent. At one end it is incessantly dissolved, at the other end it is incessantly renewed: supply and consumption being thus equalized, the cloud appears as changeless as the mountain to which it seems to cling. When the red sun of the evening shines upon these cloud-streamers they resemble vast torches with their flames blown through the air.

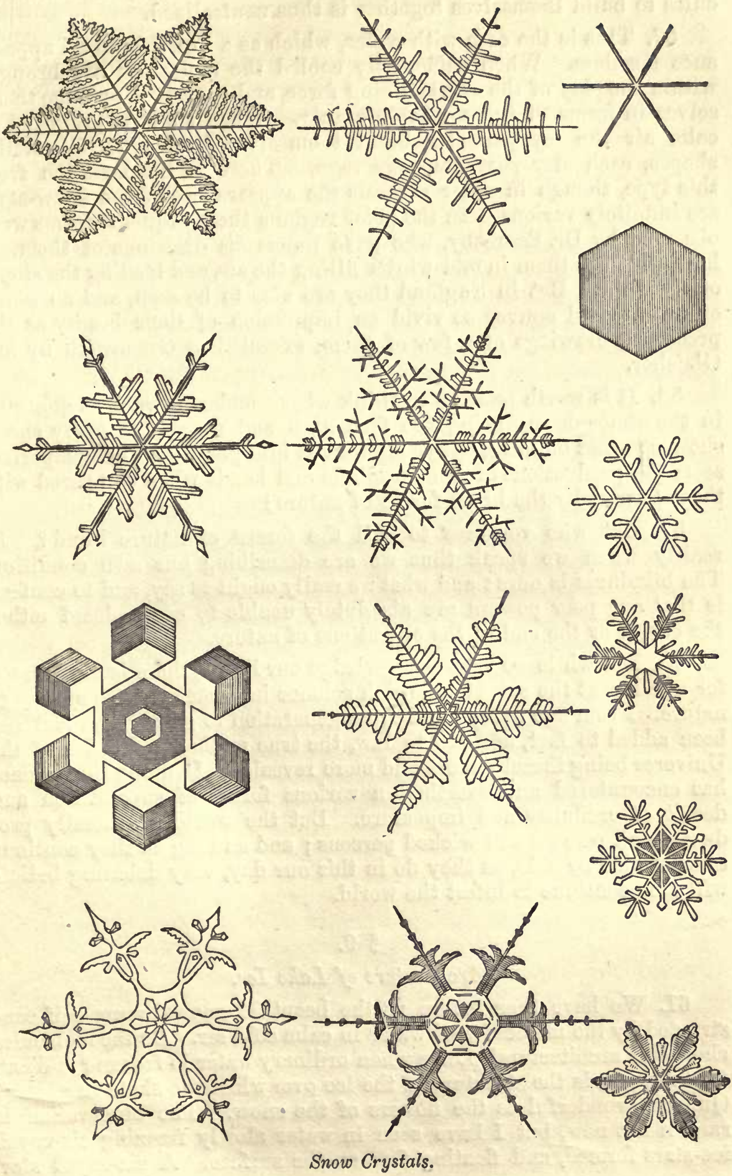
§ 8.

Architecture of Snow.

54. We now resemble persons who have climbed a difficult peak and thereby earned the enjoyment of a wide prospect. Having made ourselves masters of the conditions necessary to the production of mountain snow, we are able to take a comprehensive and intelligent view of the phenomena of glaciers.

55. A few words are still necessary as to the formation of snow. The molecules and atoms of all substances, when allowed free play, build themselves into definite and, for the most part, beautiful forms called crystals. Iron, copper, gold, silver, lead, sulphur, when melted and permitted to cool gradually all show this crystallizing power. The metal bismuth shows it in a particularly striking manner, and when properly fused and solidified self-built crystals of great size and beauty are formed of this metal.

56. You have heard of the force of gravitation, and you know that it consists of an attraction of every particle of matter for every other particle. You know that planets and moons are held in their orbits by this attraction. But gravitation is a very simple affair compared to the force or rather forces of crystallization. For here the ultimate particles of matter, inconceivably small as they are, show themselves possessed of attractive and repellent poles, by the mutual action of which the shape and structure of the crystal are determined. In the solid condition the attracting poles are rigidly locked together; but if sufficient heat be applied the bond of union is dissolved, and in the state of fusion the poles are pushed so far asunder as to be practi-



Snow Crystals.

cally out of each other's range. The natural tendency of the molecules to build themselves together is thus neutralized.

57. This is the case with water, which as a liquid is to all appearance formless. When sufficiently cooled the molecules are brought within the play of the crystallizing force, and they then arrange themselves in forms of indescribable beauty. When snow is produced in calm air the icy particles build themselves into beautiful stellar shapes, each star possessing six rays. There is no deviation from this type, though in other respects the appearances of the snow-stars are infinitely various. In the polar regions these exquisite forms were observed by Dr. Scoresby, who gave numerous drawings of them. I have observed them in mid-winter filling the air, and loading the slopes of the Alps. But in England they are also to be seen, and no words of mine could convey so vivid an impression of their beauty as the preceding drawings of a few of them, executed at Greenwich by Mr. Glaisher.

58. It is worth pausing to think what wonderful work is going on in the atmosphere during the formation and descent of every snow-shower: what building power is brought into play! and how imperfect seem the productions of human minds and hands when compared with those formed by the blind forces of nature!

59. But who ventures to call the forces of nature blind? In reality when we speak thus we are describing our own condition. The blindness is ours; and what we really ought to say, and to confess, is that our poor powers are absolutely unable to comprehend either the origin or the end of the operations of nature.

60. But while we thus acknowledge our limits, there is also reason for wonder at the extent to which science has mastered the system of nature. From age to age, and from generation to generation, fact has been added to fact, and law to law, the true method and order of the Universe being thereby more and more revealed. In doing this science has encountered and overthrown various forms of superstition and deceit, of credulity and imposture. But the world continually produces weak persons and wicked persons; and as long as they continue to exist side by side, as they do in this our day, very debasing beliefs will also continue to infest the world.

§ 9.

Architecture of Lake Ice.

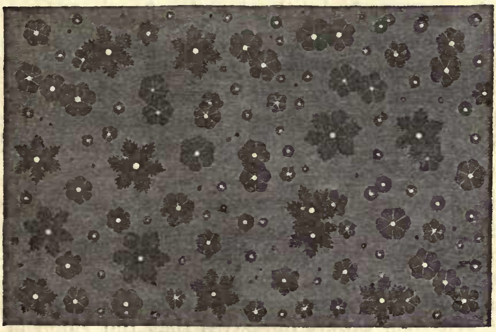
61. We have thus before us the beautiful snow-flowers self-constructed by the molecules of water in calm cold air. Do the molecules show this architectural power when ordinary water is frozen? What, for example, is the structure of the ice over which we skate in winter? Quite as wonderful as the flowers of the snow. The observation is rare, if not new, but I have seen in water slowly freezing six-rayed ice-stars formed, and floating free on the surface. A six-rayed star,

moreover, is typical of the construction of all our lake ice. It is built up of such forms wonderfully interlaced.

62. Take a slab of lake ice and place it in the path of a concentrated sunbeam. Watch the track of the beam through the ice. Part of the beam is stopped, part of it goes through; the former produces internal liquefaction, the latter has no effect whatever upon the ice. But the liquefaction is not uniformly diffused. From separate spots of the ice little shining points are seen to sparkle forth. Every one of those points is surrounded by a beautiful liquid flower with six petals.

63. Ice and water are so optically alike that unless the light fall properly upon these flowers you cannot see them. But what is the central spot? A vacuum. Ice swims on water because bulk for bulk it is lighter than water; so that when ice is melted it shrinks in size. Can the liquid flowers then occupy the whole space of the ice melted? Plainly no. A little empty space is formed with the flowers, and this space, or rather its surface, shines in the sun with the lustre of burnished silver.

64. Annexed is a very imperfect sketch of these beautiful figures.



Liquid Flowers in Lake Ice.

65. Here we have a reversal of the process of crystallization. The searching solar beam is delicate enough to take the molecules down without deranging the order of their architecture. Try the experiment for yourself with a pocket-lens on a sunny day. You will not find the flowers confused; they all lie parallel to the surface of freezing. In this exquisite way every bit of the ice over which our skaters glide in winter is put together.

66. I said above that a portion of the sunbeam was stopped by the ice and liquefied it. What is this portion? The dark rays of the sun. The great body of the light rays, and even a portion of the dark ones, pass through the ice without losing any of their heating power.

When properly concentrated on combustible bodies, after having passed through the ice, their burning power becomes manifest.

67. And the ice itself may be employed to concentrate them. With an ice-lens in the polar regions Dr. Scoresby has often concentrated the sun's rays so as to make them burn wood, fire gunpowder, and melt lead; thus proving that the heating power is retained by the rays, even after they have passed through so cold a substance.

§ 10.

The Source of the Arveiron. Ice Pinnacles, Towers, and Chasms of the Glacier des Bois. Passage to the Montanvert.

68. And now let us get to work. Through the village of Chamouni, in Savoy, a river rushes which is called the Arve. Let us trace this river backwards from Chamouni. At a little distance from the village the river forks; one of its branches still continues to be called the Arve, the other is the Arveiron. Following this latter you come to what is called the source of the Arveiron—a short hour's walk from Chamouni. Here, as in the case of the Rhone already referred to, you are fronted by a huge mass of ice, the end of a glacier, and from an arch in the ice the Arveiron issues. Do not trust the arch in summer. Its roof falls at intervals with a startling crash, and would infallibly crush any person on whom it might fall.

69. We must now be observant. Looking about us here, we find in front of the ice curious heaps and ridges of débris, which are more or less concentric. These are the *terminal moraines* of the glacier. We shall examine them subsequently.

70. We now turn to the left, and ascend the slope beside the glacier. As we ascend we get a better view, and find that the ice here fills a narrow valley. We come upon another singular ridge, not of fresh débris, like those lower down, but covered in part with trees, and appearing to be literally as "old as the hills." It tells a wonderful tale. We soon satisfy ourselves that the ridge is an ancient moraine, and at once conclude that the glacier, at some former period of its existence, was vastly larger than it is now. This old moraine stretches right across the main valley, and abuts against the mountains at the opposite side.

71. Having passed the terminal portion of the glacier, which is covered with rubbish, we find ourselves beside a very wonderful exhibition of ice. The glacier descends a steep gorge, and in doing so is riven and broken in the most extraordinary manner. Here are towers, and pinnacles, and fantastic shapes wrought out by the action of the weather, which put one in mind of rude sculpture. Annexed is a sketch of one of them. From deep chasms in the ice issues a delicate shimmer of blue light. At times we hear a sound like that of thunder, which arises either from the falling of a tower of ice, or from the

tumble of a huge stone into a chasm. The glacier maintains this wild and chaotic character for some time; and the best iceman would find himself defeated in any attempt to get along it.

Ice Figure on the Glacier des Bois.

72. We reach a place called the Chapeau, where, if we wish, we can have refreshment in a little mountain hut. We then pass the *Mauvais Pas*, a precipitous rock, on the face of which steps are hewn, and the unpractised traveller is assisted by a rope. We pursue our journey, partly along the mountain side, and partly along a ridge of singularly artificial aspect—a *lateral moraine*. We at length face a house perched upon an eminence at the opposite side of the glacier. This is the auberge of the Montanvert, well known to all visitors to this portion of the Alps.

73. Here we cross the glacier. I should have told you that its lower part, including the broken portion we have passed, is called the Glacier des Bois; while the place that we are now about to cross is the beginning of the Mer de Glace. You feel that this term is not quite appropriate, for the glacier here is much more like a *river* of ice than a sea. The valley which it fills is about half a mile wide.

74. The ice may be riven where we enter upon it, but with the necessary care there is no difficulty in crossing this portion of the Mer de Glace. The clefts and chasms in the ice are called *crevasses;* we shall make their acquaintance on a grander scale by-and-by.

75. Look up and down this side of the glacier. It is considerably riven, but as we advance the crevasses will diminish, and we shall find very few of them at the other side. Note this for future use. The ice is at first dirty; but the dirt soon disappears, and you come upon the clean crisp surface of the glacier. You have already noticed that the clean ice is white, and that from a distance it resembles snow rather than ice. This is caused by the breaking up of the surface by the solar heat. When you pound transparent rock-salt into powder it is as white as table-salt, and it is the minute fissuring of the surface of the glacier by the sun's rays that causes it to appear white. *Within* the glacier the ice is transparent. After an exhilarating passage we get upon the opposite lateral moraine, and ascend the steep slope from it to the Montanvert Inn.

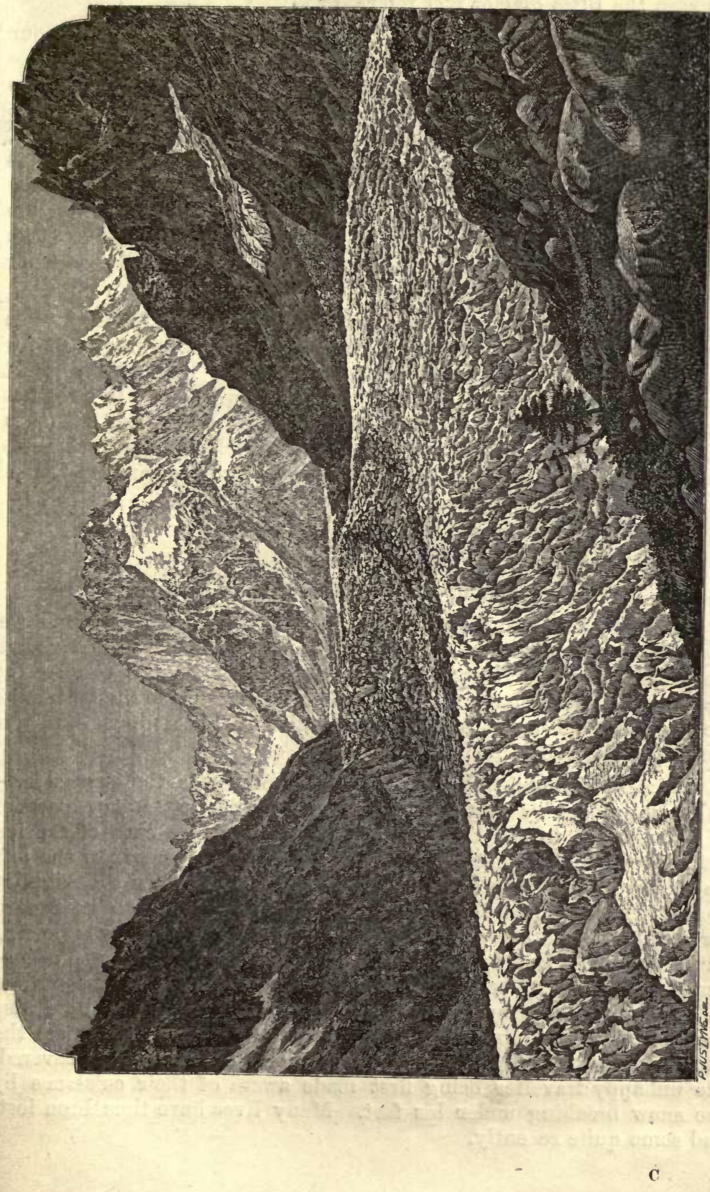
§ 11.

The Mer de Glace and its Sources: Our First Climb to the Cleft Station.

76. Here the view before us is very grand. We look across the glacier at the beautiful pyramid of the Aiguille du Dru; and to the right at the Aiguille des Charmoz, with its sharp pinnacles bent as if they were ductile. Looking straight up the glacier the view is bounded by the great crests called La Grande Jorasse, nearly 14,000 feet high. Our object now is to get into the very heart of the mountains, and to pursue to its origin the wonderful frozen river which we have just crossed.

77. Starting from the Montanvert with the glacier below us to our left, we soon reach some rocks resembling the Mauvais Pas; they are called *les Ponts*. We cross them and reach *l'Angle*, where we quit the land for the ice. We walk up the glacier, but before reaching the promontory called Trélaporte, we take once more to the mountain side; for though this path has been forsaken on account of its danger, for the sake of knowledge we are prepared to incur danger to a reasonable extent. A little glacier reposes on the slope to our right. We may see a huge boulder or two poised on the end of the glacier, and, if fortunate, also see the boulder liberated and plunging violently down the slope. Presence of mind is all that is necessary to render our safety certain; but travellers do not always show presence of mind, and hence the path which formerly led over this slope has been forsaken. The whole slope is cumbered by masses of rock which this little glacier has sent down. These I wished you to see; by-and-by they shall be fully accounted for.

78. Above Trélaporte to the right you see a most singular cleft in the rocks, in the middle of which stands an isolated pillar, hewn out by the weather. Our next object is to get to the tower of rock to the left of that cleft, for from that position we shall gain a most commanding and instructive view of the Mer de Glace and its sources.



The Mer de Glace, showing Mont Tacul and the Grande Jorasse, with our Cleft above Trélaporte to the Right.

79. The cleft referred to, with its pillar, may be seen to the right of the preceding engraving of the Mer de Glace. Below the cleft is also seen the little glacier just referred to.

80. We may reach this cleft by a steep gully, visible from our present position, and leading directly up to the cleft. But these gullies, or couloirs, are very dangerous, being the pathways of stones falling from the heights. We will therefore take the rocks to the left of the gully, by close inspection ascertain their assailable points, and there attack them. In the Alps as elsewhere wonderful things may be done by looking steadfastly at difficulties, and testing them wherever they appear assailable. We thus reach our station, where the glory of the prospect, and the insight that we gain as to the formation of the Mer de Glace, far more than repay us for the labour of our ascent.

81. For we see the glacier below us, stretching its frozen tongue downwards past the Montanvert. And we now find this single glacier branching out into three others, some of them wider than itself. Regard the branch to the right, the Glacier du Géant. It stretches smoothly up for a long distance, then becomes disturbed, and then changes to a great frozen cascade, down which the ice appears to tumble in wild confusion. Above the cascade you see an expanse of shining snow, occupying an area of some square miles.

§ 12.

Ice-cascade and Snows of the Col du Géant.

82. Instead of climbing to the height where we now stand we might have continued our walk upon the Mer de Glace, turned round the promontory of Trélaporte, and walked right up the Glacier du Géant. We should have found ice under our feet up to the bottom of the cascade. It is not so compact as the ice lower down, but you would not think of refusing to call it ice.

83. And with the aid of an axe to cut steps in the steeper ice-walls and slopes we might work our way to the top of the cascade. If we ascended to the right we should have to take care of the ice avalanches which sometimes thunder down the slopes; if to the left we should have to take care of the stones let loose from the Aiguille Noire. After we had cleared the cascade we should have to beware for a time of the crevasses, which for some distance above the fall yawn terribly. But by caution we could get round them, and sometimes cross them by bridges of snow. Here the skill and knowledge to be acquired only by long practice come into play; and here also the use of the Alpine rope suggests itself. For not only are the snow bridges often frail, but whole crevasses are sometimes covered, the unhappy traveller being first made aware of their existence by the snow breaking under his feet. Many lives have thus been lost, and some quite recently.

84. Once upon the plateau above the ice-fall we find the surface totally changed. Below the fall we walked upon ice; here we are upon snow. After a gentle but long ascent we reach a depression of the ridge which bounds the snow-field at the top, and now look over Italy. We stand upon the famous Col du Géant.

85. They were no idle scamperers on the mountains that made these wild recesses first known; it was not the desire for health which now brings some, or the desire for grandeur and beauty which brings others, or the wish to be able to say that they have climbed a mountain or crossed a col, which I fear brings a good many more; it was a desire for *knowledge* that brought the first explorers here, and on this Col the celebrated De Saussure lived for seventeen days making scientific observations.

§ 13.

Questioning the Glaciers.

86. I would now ask you to consider for a moment the facts which such an excursion places in our possession. The snow through which we have in idea trudged, and in which we have left the deep traces of our footsteps, is the snow of last winter and spring. Had we placed last August a proper mark upon the surface of the snow we should find it this August at a certain depth beneath the surface. A good deal has been melted by the summer sun, but a good deal of it remains, and it will continue until the snows of the coming winter fall and cover it. This again will be in part preserved till next August, a good deal of it remaining until it is covered by the snow of the subsequent winter. We thus arrive at the certain conclusion that on the plateau of the Col du Géant *the quantity of snow that falls annually exceeds the quantity melted.*

87. Had we come in the month of April or May we should have found the glacier below the ice-fall also covered with snow, now entirely cleared away by the heat of summer. Nay more, the ice there is obviously melting, forming running brooks which cut channels in the ice, and expand here and there into small blue-green lakes. Hence you conclude with certainty that below the ice-fall *the quantity of frozen material falling upon the glacier is less than the quantity melted.*

88. And this forces upon us another conclusion: between the glacier below the ice-fall and the plateau above it there must exist a line where the quantity of snow which falls *is exactly equal* to the quantity annually melted. This is the *snow-line.* On some glaciers it is quite distinct, and it would be distinct here were the ice less broken and confused than it actually is.

89. The French term *Névé* is applied to the glacial region above the snow-line, while the word *glacier* is restricted to the ice below it. Thus the snows of the Col du Géant constitute the névé of the Glacier du Géant, and in part, the névé of the Mer de Glace.

90. But if every year thus leaves a residue of snow upon the plateau of the Col du Géant, it necessarily follows that the plateau must get annually higher, *provided the snow remains upon it.* Equally certain is the conclusion that the whole length of the glacier below the cascade must sink gradually lower *if the waste of annual melting be not made good.* Supposing two feet of snow a year to remain upon the Col; this would raise it to a height far surpassing that of Mont Blanc in five thousand years. Such accumulation must take place if the snow remain upon the Col; but the accumulation does *not* take place, hence the snow does not remain on the Col. The question then is, whither does it go?

§ 14.

Branches and Medial Moraines of the Mer de Glace from the Cleft Station.

91. Let us sink the question for a moment, and gather from the scene before us knowledge which will help us to solve it. Look at that ice-valley in front of us, stretching up between Mont Tacul and the Aiguille de Léchaud, to the base of the great ridge called the Grande Jorasse. This is called the Glacier de Léchaud. It receives at its head the snows of the Jorasse and of Mont Mallet, and joins the Glacier du Géant at the promontory of the Tacul. The glaciers seem welded together where they join, but they continue distinct. Between them you clearly trace a stripe of débris; you trace a similar though smaller stripe from the junction of the Glacier du Géant with the Glacier des Périades at the foot of the Aiguille Noire, which you follow all along the Mer de Glace.

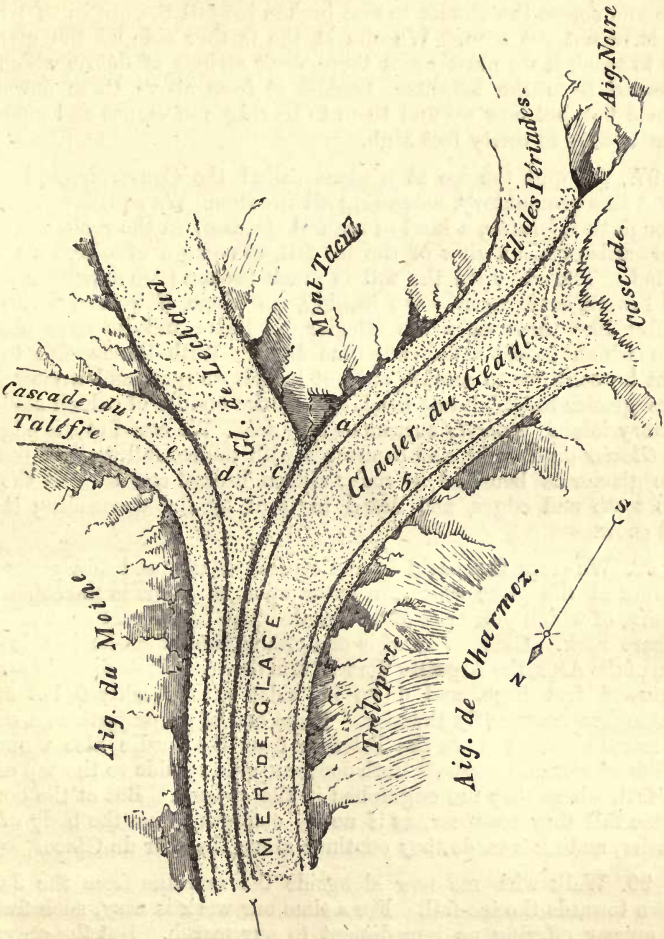
92. We also see another glacier, or a portion of it, to the left, falling apparently in broken fragments through a narrow gorge, and joining the Léchaud, and from their point of junction also a stripe of débris runs downwards along the Mer de Glace. Beyond this again we notice another stripe, which seems to begin at the bottom of the ice-fall, rising as it were from the body of the glacier. Beyond all of these we can notice the lateral moraine of the Mer de Glace.

93. These stripes are the *Medial Moraines* of the Mer de Glace. We shall learn more about them immediately.

94. Annexed is a sketch-plan of the glacier and its moraines taken from our present commanding position.

95. And now, having informed our minds by these observations, let our eyes wander over the whole glorious scene, the splintered peaks and the hacked and jagged crests, the far-stretching snow-fields, the smaller glaciers which nestle on the heights, the deep-blue heaven and the sailing clouds. Is it not worth some labour to gain command of such a scene? But the delight it imparts is heightened by the fact that we did not come expressly to see it; we came to instruct ourselves about the glacier, and this high enjoyment is an incident of

our labour. You will find it thus through life; without honest labour there can be no deep joy.



Sketch-plan, showing the Moraines a b c d e of the Mer de Glace.

§ 15.

The Talèfre and the Jardin. Work among the Crevasses.

96. And now let us descend to the Mer de Glace, for I want to take you across the glacier to that broken ice-fall the origin of which we have not yet seen. We aim at the farther side of the glacier, and to reach it we must cross those dark stripes of débris which we observed from the heights. Looked at from above these moraines seemed flat, but now we find them to be ridges of stones and rubbish, from twenty to thirty feet high.

97. We quit the ice at a place called the Couvercle, and wind round this promontory, ascending all the time. We squeeze ourselves through the *Egralets*, a kind of natural staircase in the rock, and soon afterwards obtain a view of the ice-fall, the origin of which we wish to find. The ice upon the fall is much broken; we have pinnacles and towers, some erect, some leaning, and some, if we are fortunate, falling like those upon the Glacier des Bois; and we have chasms from which issues a delicate blue light. With the ice-fall to our right we continue to ascend, until at length we command a view of a huge glacier basin, almost level, and on the middle of which stands a solitary island, entirely surrounded by ice. We stand at the edge of the *Glacier du Talèfre*, and connect it with the ice-fall we have passed. The glacier is bounded by rocky ridges, hacked and torn at the top into teeth and edges, and fluted in front by the descending stones and snow.

98. We cross the basin to the central island, and find grass and flowers at the place where we enter upon it. This is the celebrated *Jardin*, of which you have often heard. The upper part of the Jardin is bare rock. Close at hand is one of the noblest peaks in this portion of the Alps, the Aiguille Verte. It is between thirteen and fourteen thousand feet high, and down its sides, after freshly-fallen snow, avalanches incessantly thunder. From one of its projections a streak of moraine starts down the Talèfre; from the Jardin also a similar streak of moraine issues. Both continue side by side to the top of the ice-fall, where they are engulphed in the chasms. But at the bottom of the fall they reappear, as if newly emerging from the body of the glacier, and afterwards they continue along the Mer de Glace.

99. Walk with me now alongside the moraine from the Jardin down towards the ice-fall. For a time our work is easy, such fissures as appear offering no impediment to our march. But the crevasses become gradually wider and wilder, following each other at length so rapidly as to leave merely walls of ice between them. Here perfect steadiness of foot is necessary—a slip would be death. We look towards the fall, and observe the confusion of walls and blocks and chasms below us increasing. At length prudence and reason cry "Halt!" We may swerve to the right or to the left, and making

our way along crests of ice, with chasms on both hands, reach either the right lateral moraine or the left lateral moraine of the glacier.

100. And now for home, looking at the Tacul on our way. Here we see the actual junction of the moraines of the Géant and the Léchaud. They have brought down mighty stones, under one of which I had a very hard bed on the night of the 24th of July, 1857. Notice particularly a precipice of ice—the naked side of the glacier which is here displayed. We shall turn it to account subsequently.

§ 16.

First Questions regarding Glacier Motion. Drifting of Bodies buried in a Crevasse.

101. But what are these lateral moraines? As you and I go from day to day along the glaciers, their origin is gradually made plain. We see at intervals the stones and rubbish descending from the mountain sides and arrested by the ice. All along the fringe of the glacier the stones and rubbish fall, and it soon becomes evident that we have here the source of the lateral moraines.

102. But how are the medial moraines to be accounted for? How does the débris range itself upon the glacier in stripes some hundreds of yards from its edge, leaving the space between them and the edge clear of rubbish? Some have supposed the stones to have rolled over the glacier from the sides, but the supposition will not bear examination. Call to mind now our reasoning regarding the excess of snow which falls above the snow-line, and our subsequent question, How is the snow disposed of. Can it be that the entire mass is moving slowly downwards? If so, the lateral moraines would be carried along by the ice on which they rest, and when two branch glaciers unite they would lay their adjacent lateral moraines together to form a medial moraine upon the trunk glacier.

103. There is, in fact, no way that we can see of disposing of the excess of snow above the snow-line; there is no way of making good the constant waste of the ice below the snow-line; there is no way of accounting for the medial moraines of the glacier, but by supposing that from the highest snow-fields of the Col du Géant, the Léchaud, and the Talèfre, to the extreme end of the Glacier des Bois, the whole mass of frozen matter is moving downwards.

104. If you were older it would give me pleasure to take you up Mont Blanc. Starting from Chamouni we should first pass through woods and pastures, then up the steep hill-face with the Glacier des Bossons to our right, to a rock known as the *Pierre Pointue;* thence to a higher rock called the *Pierre l'Echelle*, because here a ladder is usually placed to assist in crossing the chasms of the glacier. At the Pierre l'Echelle we should strike the ice, and passing under the

Aiguille du Midi, which towers to the left, and which sometimes sweeps a portion of the track with stone avalanches, we should cross the Glacier des Bossons; amid heaped-up mounds and broken towers of ice; up steep slopes; over chasms so deep that their bottoms are hid in darkness, to the rocks of the Grands Mulets, which form a kind of barren islet in the icy sea. Thence to the higher snow-fields, crossing the *Petit Plateau*, which we should find cumbered by blocks of ice. Looking to the right, we should see whence they came, for rising here with threatening aspect high above us are the broken ice-crags* of the Dome du Gouté. The guides wish to pass this place in silence, and it is just as well to humour them, however much you may doubt the competence of the human voice to bring the ice-crags down. From the Petit Plateau a steep snow-slope would carry us to the Grand Plateau, and at day-dawn I know nothing in the whole Alps more grand and solemn than this place.

105. One object of our ascent would be now attained; for here at the head of the Grand Plateau, and at the foot of the final slope of Mont Blanc, I should show you a great crevasse, into which three guides were poured by an avalanche in the year 1820.

106. Is this language correct? A crevasse hardly to be distinguished from the present one undoubtedly existed here in 1820. But was it the identical crevasse now existing? Is the ice riven here to-day the same as that riven fifty-one years ago? By no means. How is this proved? By the fact that more than forty years after their interment, the remains of those three guides were found near the end of the Glacier des Bossons, many miles from the existing crevasse.

107. The same observation proves to demonstration that it is the ice near the *bottom* of the higher névé that becomes the *surface-ice* of the glacier near its end. The uncompensated waste of the surface below the snow-line brings the deeper portions of the ice more and more to the light of day.

108. There are numerous obvious indications of the existence of glacier motion, though it is too slow to catch the eye at once. The crevasses change within certain limits from year to year, and sometimes from month to month; and this could not be if the ice did not move. Rocks and stones also are observed, which have been plainly torn from the mountain sides. Blocks seen to fall from particular points are afterwards observed lower down. On the moraines rocks are found of a totally different mineralogical character from those composing the mountains right and left; and in all such cases hills or strata of the same character are found bordering the glacier higher up. Hence the conclusion that the foreign boulders have been *floated* down by the ice. Further, the ends or "snouts" of many glaciers

* Called *séracs* from their resemblance in shape and colour to an inferior kind of curdy cheese called by this name at Chamouni.

act like ploughshares on the land in front of them, overturning with slow but merciless force huts and châlets that stand in their way. Facts like these have been long known to the inhabitants of the High Alps, who were thus made acquainted in a vague and general way with the motion of the glaciers.

§ 17.

The Motion of Glaciers. Measurements by Hugi and Agassiz. Drifting of Huts on the Ice.

109. But the growth of knowledge is from vagueness towards precision, and exact determinations of the rate of glacier motion were soon desired. With reference to such measurements one glacier in the Bernese Oberland will remain for ever memorable. From the little town of Meyringen in Switzerland you proceed up the valley of Hasli, past the celebrated waterfall of Handeck, where the river Aar plunges into a chasm more than 200 feet deep. You approach the Grimsel Pass, but instead of crossing it you turn to the right and follow the course of the Aar upwards. Like the Rhone and the Arveiron you find the Aar issuing from a glacier.

110. Get upon the ice, or rather upon the deep moraine shingle which covers the ice, and walk upwards. It is hard walking, but after some time you get clear of the rubbish, and on to a wide glacier with a great medial moraine running along its back. This moraine is formed by the junction of two branch glaciers, the Lauteraar and the Finsteraar, which unite at a promontory called the Abschwung to form the trunk glacier of the Unteraar.

111. On this great medial moraine in 1827 an intrepid and enthusiastic Swiss professor, Hugi, of Solothurm (French Soleure), built a hut with a view to observations upon the glacier. His hut moved, and he measured its motion. In the three years—from 1827 to 1830—it had moved 330 feet downwards. In 1836 it had moved 2354 feet; and in 1841 M. Agassiz found it 4712 feet below its first position.

112. In 1840 M. Agassiz himself and some bold companions took shelter under a great overhanging slab of rock on the same moraine, to which they added side walls and other means of protection. And because he and his comrades came from Neufchatel, the hut was called long afterwards the "Hôtel des Neuchâtelois." Two years subsequent to its erection M. Agassiz found that the "hotel" had moved 486 feet downwards.

§ 18.

Precise Measurements of Agassiz and Forbes. Motion of a Glacier proved to resemble the Motion of a River.

113. We now approach an epoch in the scientific history of glaciers. Had the first observers been practically acquainted with the instruments of precision used in surveying, *accurate* measurements of the motion of

glaciers would probably have been earlier executed. We are now on the point of seeing such instruments introduced almost simultaneously by M. Agassiz on the glacier of the Unteraar, and by Professor Forbes on the Mer de Glace. Attempts had been made by M. Escher de la Linth to determine the motion of a series of wooden stakes driven into the Aletsch glacier, but the melting was so rapid that the stakes soon fell. To remedy this M. Agassiz in 1841 undertook the great labour of carrying boring tools to his "hotel," and piercing the Unteraar glacier at six different places to a depth of ten feet, in a straight line across the glacier. Into the holes six piles were so firmly driven that they remained in the glacier for a year, and in 1842 the displacements of all six were determined. They were found to be 160 feet, 225 feet, 269 feet, 245 feet, 210 feet, and 125 feet, respectively.

114. A great step is here gained. You notice that the middle numbers are the largest. They correspond to the central portion of the glacier. Hence, these measurements conclusively establish, not only the fact of glacier motion, but that *the centre of the glacier, like that of a river, moves more rapidly than the sides.*

115. With the aid of trained engineers M. Agassiz followed up these measurements in subsequent years. His researches are recorded in a work entitled 'Système Glacier,' which is accompanied by a very noble Atlas of the Glacier of the Unteraar, published in 1847.

116. These determinations were made by means of a theodolite, of which I will give you some notion immediately. The same instrument was employed the same year by the late Principal Forbes upon the Mer de Glace. He established independently the greater central motion. He showed, moreover, that it is not necessary to wait a year, or even a week, to determine the motion of a glacier; with a correctly-adjusted theodolite he was able to determine the motion of various points of the Mer de Glace from day to day. He affirmed, and with truth, that the motion of the glacier might be determined from hour to hour. We shall prove this farther on (125). Professor Forbes also triangulated the Mer de Glace, and laid down an excellent map of it. His first observations and his survey are recorded in a celebrated book published in 1843, and entitled 'Travels in the Alps.'

117. These observations were also followed up in subsequent years, the results being recorded in a series of detached letters and essays of great interest. These were subsequently collected in a volume entitled 'Occasional Papers on the Theory of Glaciers,' published in 1859. The labours of Agassiz and Forbes are the two chief sources of our knowledge of glacier phenomena.

§ 19.

The Theodolite and its Use. Our own Measurements.

118. My object thus far is attained. I have given you proofs of glacier motion, and a historic account of its measurement. And now we must try to add a little to the knowledge of glaciers by our own labours on the ice. Resolution must not be wanting at the commencement of our work, nor steadfast patience during its prosecution. Look then at this theodolite; it consists mainly of a telescope and a graduated circle, the telescope capable of motion up and down, and the circle, carrying the telescope along with it, capable of motion right and left. When desired to make the motion exceedingly fine and minute, suitable screws, called tangent screws, are employed. The instrument is supported by three legs, movable, but firm when properly planted.

119. Two spirit levels are fixed at right angles to each other on the circle just referred to. Practice enables one to take hold of the legs of the instrument, and so to fix them that the circle shall be nearly horizontal. By means of four levelling screws we render it *accurately* horizontal. Exactly under the centre of the instrument is a small hook from which a plummet is suspended; the point of the bob just touches a rock on which we make a mark; or if the earth be soft underneath, we drive a stake into it exactly under the plummet. By re-suspending the plummet at any future time we can find to a hairsbreadth the position occupied by the instrument to-day.

120. Look through the telescope; you see it crossed by two fibres of the finest spider's thread. In actual work we should first direct the telescope across the glacier, until the intersection of the two fibres accurately covers some well-defined point of rock or tree at the other side of the valley. This we sketch with its surroundings in a note book, so that we shall immediately recognize it on our return to this place. Imagine a straight line drawn from the centre of the telescope to this point, and that this line is permitted to drop straight down upon the glacier, every point of it falling as a stone would fall; along such a line we have now to fix a series of stakes.

121. A trained assistant is already upon the glacier. He erects his staff and stands straight behind it; the telescope is lowered without swerving to the right or to the left; in mathematical language it remains *in the same vertical plane*. The crossed fibres of the telescope probably strike the ice a little away from the staff of the assistant; by a wave of the arm he moves right or left; he may move too much, so we wave him back again. After a trial or two he knows whether he is near the proper point, and if so makes his motions small. He soon exactly strikes the point covered by the intersection of the fibres. A signal is made which tells him that he is right; he pierces the ice with an auger and drives in a stake. He then goes forward and in precisely the same manner takes up another point.

After one or two stakes have been driven in, the assistant is able to take up the other points very rapidly. Any requisite number of stakes may thus be fixed in a straight line across the glacier.

122. Next morning we measure the motion of all the stakes. The theodolite is mounted in its former position and carefully levelled. The telescope is directed first upon the mark at the opposite side of the valley, being moved by a tangent screw until the point where the spider's threads cross each other accurately covers the point at the other side. The telescope is then lowered to the first stake, beside which our trained assistant is already standing. He is provided with a staff with feet and inches marked on it. A glance shows us that the stake has moved down. By our signals the assistant recovers the point from which we started yesterday, and then determines the distance from this point to the stake. It is, say, 6 inches; through this distance, therefore, the stake has moved.

123. We are careful to note the hour and minute at which each stake is driven in and the hour and the minute when its distance from its first position was measured; this enables us to calculate the accurate daily motion of the point in question. The distances through which all the other points have moved, are determined in precisely the same way.

124. Thus we shall proceed to work, first making perfectly clear to our minds what is to be done, and then loyally making sure that it shall be accurately done. To give our work reality, I will here record the actual measurements executed, and the actual thoughts suggested, on the Mer de Glace in 1857. The only unreality that I would ask you to allow, is that you and I are supposed to be making the observations together. The labour of measuring was undertaken for the most part by Mr. Hirst.

§ 20.

Motion of the Mer de Glace.

125. On the 14th of July, then, we find ourselves at the end of the Glacier des Bois, not far from the source of the Arveiron. We direct our telescope across the glacier, and fix the intersection of its spider's threads accurately upon the edge of a pinnacle of ice. We leave the instrument untouched, looking through it from hour to hour. The edge of ice moves slowly, but plainly, past the cross hairs, and at the end of three hours we assure ourselves that the motion has amounted to several inches. While standing near the vault of the Arveiron, and talking about going into it, its roof gives way, and falls with the sound of thunder. It is not, therefore, without reason that I warned you against entering these vaults in summer.

126. We ascend to the Montanvert Inn, fix on it as a residence, and then descend to the lateral moraine of the glacier a little below the Inn. Here we erect our theodolite, and mark its exact position by a plummet. We must first make sure that our line is perpen-

dicular, or nearly so, to the axis or middle line of the glacier. We send an instructed assistant to the middle; he there lays down a long staff or a rope in the direction of the axis, assuring himself by looking up and down, that it is the true direction. With a second staff in his hand, pointed towards our theodolite, he shifts his position until the second staff is perpendicular to the first. Here he gives us a signal. We direct our telescope upon him, and then gradually raising its end in a vertical plane we find, and note by sketching, a suitable point at the other side of the glacier. This point known, and our plummet mark known, we can on any future day find our line. To render the measurements more intelligible, I here append an outline diagram of the Mer de Glace, and of its tributaries. (See p. 30.)

127. Along the line just described ten stakes were set on the 17th of July. Their displacements were measured on the following day. Two of them had fallen, but here are the distances passed over by the eight remaining ones in twenty-four hours.

DAILY MOTION OF MER DE GLACE, July, 1857.

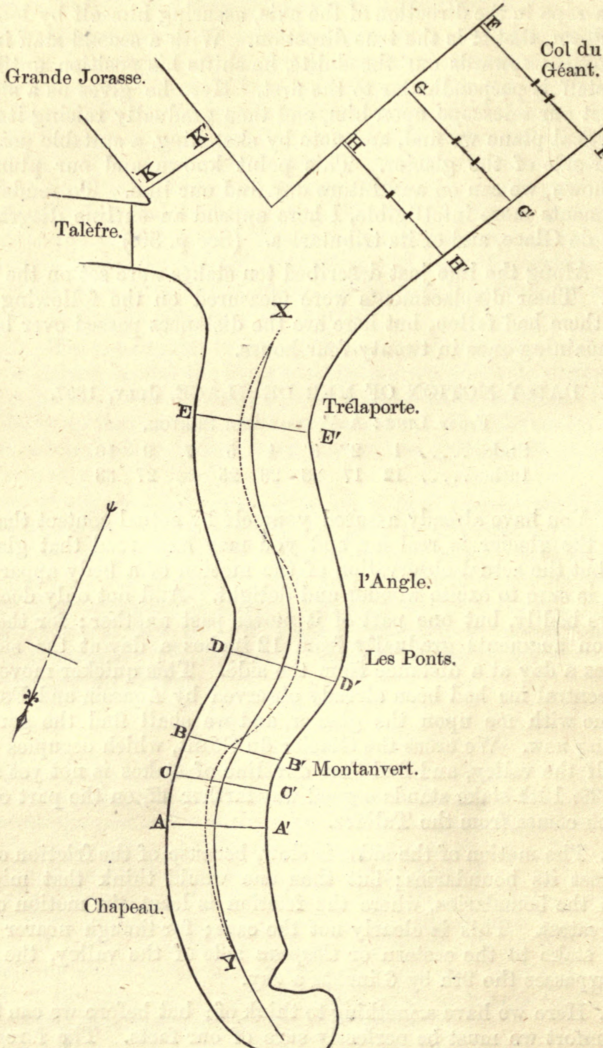
First Line: A A′ upon the Sketch.

Stake.....	1	2	3	4	5	7	9	10
Inches.....	12	17	23	26	25	26	27	33

128. You have already assured yourself by actual contact that the body of the glacier is real ice, and you may have read that glaciers move; but the actual observation of the motion of a body apparently so rigid is sure to excite wonder and delight. And not only does the ice move bodily, but one part of it moves past another; for the rate of motion augments gradually from 12 inches a day at the side to 33 inches a day at a distance from the side. This quicker movement of the central ice had been already observed by Agassiz and Forbes; but come with me upon the glacier, and we shall find the germ of something new. We cross the Glacier du Géant, which occupies more than half the valley, and find that our line of stakes is not yet at an end. The 10th stake stands a good way farther off, on the part of the ice which comes from the Talèfre.

129. The motion of the sides is slow, because of the friction of the ice against its boundaries; but then one would think that midway between the boundaries, where the friction is least, the motion ought to be greatest. This is clearly not the case; for though nearer than the 9th stake to the eastern or *Chapeau* side of the valley, the 10th stake surpasses the 9th by 6 inches a day.

130. Here we have something to think of; but before we can think with comfort we must be perfectly sure of our facts. The foregoing line ran across the glacier a little below the Montanvert. We will run another line of stakes across a little way above the hotel. On the 18th of July we set out this line, and to multiply our chances of discovery we place along it 31 stakes. On the subsequent day five of these



Outline Plan, showing the Measured Lines of the Mer de Glace and its Tributaries.

were found unfit for use. Here are the distances passed over by the remaining six-and-twenty in 24 hours.

SECOND LINE: B B′ UPON THE SKETCH.

Stake	1	2	3	4	5	6	7	8	9	10	11	12	13
Inches	8	11	12	15	15	16	17	18	19	20	20	21	21
Stake	14	15	16	17	18	19	20	21	22	23	24	25	26
Inches	21	23	23	23	21	23	21	25	22	22	23	25	26

131. Look at these numbers. The first broad fact that they reveal is the advance in the rate of motion from first to last. There are however small irregularities; from 23 inches at the 17th stake we fall to 21 inches at the 18th; from 23 inches at the 19th we fall to 21 inches at the 20th; from 25 inches at the 21st we fall to 22 inches at the 22nd and 23rd; but notwithstanding these small ups and downs, the general advance of the rate of motion is manifest. Now there may have been some slight displacement of the stakes by melting, sufficient to account for these small deviations from uniformity in the increase of the motion. But another solution is also possible. We shall afterwards learn that the glacier is retarded not only by its sides but by its bed; that the upper portions of the ice slide over the lower ones. Now if the bed of the Mer de Glace should have eminences here and there rising sufficiently near to the surface to retard the motion of the surface, they might produce the small irregularities noticed above.

132. We note particularly that the 26th stake here, like the 10th stake in our last line, stands much nearer to the eastern than to the western side of the glacier; the measurements, therefore, offer a further proof that the centre of this portion of the glacier is *not* the place of swiftest motion.

§ 21.

Unequal Motion of the two Sides of the Mer de Glace.

133. But in neither the first line nor the second have we been able to push our measurements quite across the glacier. Why? In attempting to do one thing we are often taught another, our defeats becoming in this way means of instruction. We planted our theodolite on the lateral moraine of the Mer de Glace, expecting to be able to command the glacier from side to side. But we are now undeceived; the centre of the glacier proves higher than its sides, and from our last two positions the centre cut off the view of the ice near the opposite side of the glacier. The mountain slopes, in fact, are warm in summer, and they melt the ice nearest them, thus causing a fall from the centre to the sides.

134. Yonder on the heights at the other side we see a likely place for our theodolite. We cross the glacier and plant our instrument in a position from which we sweep the glacier from side to side. Our first line was below the Montanvert, our second line above it;

this third line is exactly opposite the Montanvert; in fact the mark on which we have fixed the fibre-cross of the theodolite is a corner of one of the windows of the little inn. Along this line we fixed twelve stakes on the 20th of July. On the 21st one of them had fallen; but the velocity of the remaining eleven measured in 24 hours were found to be as follows:—

THIRD LINE: C C′ UPON THE SKETCH.

Stake	1	2	3	4	5	6	7	8	9	10	11
Inches.....	20	23	29	30	34	28	25	25	25	18	9

135. Both the first stake and the eleventh in this series stood near the side of the glacier. On the eastern side the motion is 20 inches, while on the western side it is only 9. It rises on the eastern side from 20 to 34 inches at the 5th stake, which we, standing upon the glacier, can see to be much nearer to the eastern than to the western side. The united evidence of these three lines goes to prove that opposite the Montanvert, and for some distance above it and below it, *the whole eastern side of the glacier is moving more quickly than the western side.*

§ 22.

Suggestion of a new likeness of Glacier Motion to River Motion. Conjecture tested.

136. Here we have food for reflection, and facts are comparatively worthless if they do not provoke this exercise of the mind. Let us ascend to a point which commands a good view of this portion of the Mer de Glace. The ice-river we see is not straight but curved, and its curvature is *from* the Montanvert; that is to say its convex side is east, and its concave side is west. You have already pondered the fact that a glacier, *in some respects,* moves like a river. How would a river move through a curved channel? This is known. Were the ice of the Mer de Glace displaced by water, the point of swiftest motion here would not be the centre, but a point east of the centre. Can it be then that this "water-rock," as ice is sometimes called, acts in this respect also like water?

137. This is a thought suggested on the spot; it may or it may not be true, but the means of testing it are at hand. Looking up the glacier you see that towards *les Ponts* it also bends, but that there its convex curvature is towards the western side of the valley. If our surmise be true, the point of swiftest motion opposite *les Ponts* ought to lie west of the axis of the glacier. Let us test this conjecture. On the 25th of July we fix in a line across this portion of the glacier seventeen stakes; every one of them has remained firm, and on the 26th we find the motion for 24 hours to be as follows:—

FOURTH LINE: D D′ UPON THE SKETCH.

	East.														West.
Stake	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Inches.....	7	8	13	15	16	19	20	21	21	23	23	21	22	17	15

138. Inspected by the naked eye alone the stakes 10 and 11, where the glacier reaches its greatest motion, are seen to be considerably to the west of the axis of the glacier. Thus far we have a perfect verification of the guess which prompted us to make these measurements.

139. But though even now we have exceedingly strong reason for holding that the point of maximum velocity obeys the law of liquid motion, the strength of our conclusion will be doubled if we can show that the point shifts back to the east of the axis at another place of flexure. Fortunately such a place exists opposite Trélaporte. Here the convex curvature of the valley turns again to the east. Across this portion of the glacier a line was set out on the 28th of July, and from measurements on the 31st, the rate of motion per 24 hours was determined.

FIFTH LINE: E E′ UPON THE SKETCH.

	West.														East.
Stake	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Inches.....	11	14	13	15	15	16	17	19	20	19	20	18	16	15	10

140. Here, when we descend to the glacier, the mere estimate of distances by the eye shows us that the three stakes which moved fastest, *viz.* the 9th, 10th, and 11th, are all to the east of the middle line of the glacier. The demonstration that the point of swiftest motion wanders to and fro across the axis, as the flexure of the valley changes, is, therefore,—shall I say complete?

141. Not yet. For if surer means are open to us we must not rest content with estimates by the eye. We have with us a surveying chain: let us get it out and measure these lines, noting the distance of every stake from the side of the glacier. We can then compare a number of stakes on the eastern side with the same number of stakes taken at the same distances from the western side. For example, a pair of stakes, one ten yards from the eastern side and the other ten yards from the western side; another pair, one fifty yards from the eastern side and the other fifty yards from the western side, and so on, can be compared together. For the sake of easy reference let us call the points thus compared in pairs *equivalent points.*

142. There were five pairs of such points upon our Fourth Line, D D′, and here are their velocities:—

~~Eastern~~ points; motion in inches	13	15	16	18	20
~~Western~~ points ,, ,, ...	15	17	22	23	23

In every case here the stake at the eastern side moved more rapidly than the equivalent stake at the western side.

143. Applying the same analysis to our Fifth Line, E E′, we have the following series of velocities of three pairs of equivalent points:—

Eastern points; motion in inches	15	18	17
Western points ,, ,, ...	13	15	19

D

144. Here the three points on the eastern side move more rapidly than the equivalent points on the western side.

145. It is thus proved :—

1. *That opposite the Montanvert the eastern half of the Mer de Glace moves more rapidly than the western half.*

2. *That opposite* les Ponts *the western half of the glacier moves more rapidly than the eastern half.*

3. *That opposite Trélaporte the eastern half of the glacier again moves more rapidly than the western half.*

4. *That these changes in the place of greatest motion are determined by the flexures of the valley through which the Mer de Glace moves.*

§ 23.

New Law of Glacier Motion.

146. Let us look at these facts and express them in another way. Supposing the points of swiftest motion for a very great number of lines crossing the Mer de Glace to be determined; the line joining all those points together is what mathematicians would call the *locus* of the point of swiftest motion.

147. At Trélaporte this line would lie east of the centre; at the *Ponts* it would lie west of the centre; hence in passing from Trélaporte to the *Ponts* it would *cross* the centre. But at the Montanvert it would again lie east of the centre; hence between the *Ponts* and the Montanvert the centre must be crossed a second time. If there were further sinuosities upon the Mer de Glace there would be further crossings of the axis of the glacier.

148. The points on the axis which mark the transition from eastern to western bending, and the reverse, may be called *points of contrary flexure.*

149. Now what is true of the Mer de Glace is true of all other glaciers moving through sinuous valleys; so that the facts established in the Mer de Glace may be expanded into the following general law of glacier motion :—

150. *When a glacier moves through a sinuous valley the locus of the point of maximum motion does not coincide with the centre of the glacier, but, on the contrary, always lies on the convex side of the central line. The locus is therefore a curved line more deeply sinuous than the valley itself, and therefore crosses the axis of the glacier at each point of contrary flexure.*

151. The dotted line on the Outline Plan (page 30) represents the locus of the point of maximum motion, the firm line marking the centre of the glacier.

152. Substituting the word *river* for *glacier*, this law is also true. The motion of the water is ruled by precisely the same conditions as the motion of the ice.

§ 24.

153. We have now measured the rate of motion of five different lines across the trunk of the Mer de Glace. Do they all move alike? No. Like a river, a glacier at different places moves at different rates. Comparing together the points of maximum motion of all five lines, we have this result:—

MOTION OF MER DE GLACE.

At Trélaporte	20	inches a day.
At *les Ponts*	23	„ „
Above the Montanvert	26	„ „
At the Montanvert	34	„ „
Below the Montanvert	33*	„ „

154. There is thus an increase of rapidity as we descend the glacier from Trélaporte to the Montanvert; the maximum motion at the Montanvert being fourteen inches a day greater than at Trélaporte.

§ 25.

Motion of Tributary Glaciers.

155. So much for the trunk glacier; let us now investigate the branches, permitting, as we have hitherto done, reflection on known facts to precede our attempts to discover unknown ones. As we stood beside that cleft whence we had so capital a view of the Mer de Glace, we were struck by the fact that some of the tributaries of the glacier were wider than the glacier itself. Supposing water to be substituted for the ice, how do you suppose it would behave? I think you would conclude that the motion down the broad and slightly-inclined valleys of the Géant and the Léchaud would be comparatively slow, but that the water would force itself with increased rapidity through the "narrows" of Trélaporte. Let us test this notion.

156. Planting our theodolite in the shadow of Mont Tacul, and choosing a suitable point at the opposite side of the Glacier du Géant, we fix on the 29th of July a series of ten stakes across the glacier. The motion of this line in 24 hours was as follows:—

MOTION OF GLACIER DU GÉANT.

SIXTH LINE: H H′ UPON SKETCH.

Stake	1	2	3	4	5	6	7	8	9	10
Inches	11	10	12	13	12	13	11	10	9	5

157. Our conjecture is fully verified. The maximum motion here is 7 inches a day less than that of the Mer de Glace at Trélaporte (139).

* This is probably under the mark. I think it likely that the swiftest motion of this portion of the Mer de Glace in 1857 amounted to a yard in twenty-four hours.

158. And now for the Léchaud branch. On the 1st of August we fix ten stakes across this glacier above the point where it is joined by the Talèfre. Measured on the 3rd of August, and reduced to 24 hours, the motion was found to be—

MOTION OF GLACIER DE LÉCHAUD.

SEVENTH LINE: K K′ UPON SKETCH.

Stake	1	2	3	4	5	6	7	8	9	10
Inches	5	8	10	9	9	8	6	9	7	6

159. Here our conjecture is still further verified, the rate of motion being even less than that of the Glacier du Géant.

§ 26.

Lateral Compression of a Glacier.

160. With our minds furnished with the knowledge which these labours and measurements have given us, let us once more climb to our station beside the cleft under the Aiguille de Charmoz. At our first visit we saw the medial moraines of the glacier, but we knew nothing about their cause. We now know that they divide upon the trunk the tributary glaciers from each other. Cast your eye then first upon the Glacier du Géant; realize its width in its own valley; and see how much narrower it is at Trélaporte. The aspect of the Léchaud is still more surprising. The broad ice-stream is squeezed upon the Mer de Glace to a narrow white band between its bounding moraines. The Talèfre undergoes similar compression. Let us descend, shake out our chain, measure, and express in numbers the width of the tributaries, and the actual amount of compression suffered at Trélaporte.

161. We find the width of the Glacier du Géant to be 5155 links, or 1134 yards.

162. The width of the Glacier de Léchaud we find to be 3725 links, or 825 yards.

163. The width of the Talèfre we find to be 2900 links, or 638 yards.

164. The sum of the widths of the three branch glaciers is therefore 2597 yards.

165. At Trélaporte these three branches are forced through a gorge 893 yards wide, or one-third of their previous width, at the rate of 20 inches a day.

166. If we limit our view to the Glacier de Léchaud, the facts are still more astonishing. Previous to its junction with the Talèfre, this glacier has a width of 825 yards; in passing through the jaws of the granite vice at Trélaporte, its width is reduced to 88 yards, or in round numbers to one-tenth of its previous width.

167. Are we to understand by this that the ice of the Léchaud is squeezed to one-tenth of its former *volume?* By no means. It is

mainly a change of *form*, not of volume, that occurs at Trélaporte. Previous to its compression, the glacier resembles a plate of ice *lying flat* upon the bed of the glacier. After its compression it resembles a plate *fixed upon its edge*. The squeezing, doubtless, has deepened the ice.

§ 27.

Longitudinal Compression of a Glacier.

168. The ice is forced through the gorge at Trélaporte by a pressure from behind. The Glacier du Géant, immediately above Trélaporte represents a piston or a plug which drives the ice through the gorge. What effect must this pressure have upon the plug itself? Reasoning alone renders it probable that the pressure will shorten the plug; that the lower part of the Glacier du Géant will to some extent yield to the pressure from behind.

169. Let us test this notion. About three-quarters of a mile above the Tacul, and on the mountain slope to the left as we ascend, we observe a patch of verdure. Thither we climb; there we plant our theodolite, and set out across the Glacier du Géant, a line, which we will call line No. 1 (F F′ upon sketch, p. 30).

170. About a quarter of a mile lower down we find a practicable couloir on the mountain side; we ascend it, reach a suitable platform, plant our instrument, and set out a second line, No. 2 (G G′ upon sketch). We must hasten our work here, for along this couloir stones are discharged from a small glacier which rests upon the slope of Mont Tacul.

171. Still lower down by another quarter of a mile, which brings us near the Tacul, we set out a third line, No. 3 (H H′ upon sketch), across the glacier.

172. The daily motion of the centres of these three lines is as follows:—

LONGITUDINAL COMPRESSION OF GLACIER DU GÉANT.

	Inches.	Distances asunder.
No. 1	20·55	
		.. .. 545 yards.
No. 2	15·43	
		.. .. 487 „
No. 3	12·75	

173. The first line here moves 5 inches a day more than the second; and the second nearly 3 inches a day more than the third. Our reasoning is therefore confirmed. Our ice-plug, which is in round numbers 1000 yards long, is shortened by the pressure exerted on its front at the rate of about 8 inches a day.

174. A river descending the Valley du Géant would behave in substantially the same fashion. It would have its motion on approaching Trélaporte diminished, and it would pour through the defile with a velocity greater than that of the water behind.

§ 28.

Motion of Top and Bottom of Glacier.

175. But the likeness does not end here. The motion of a river is retarded by the friction against its bed. Two observers, *viz.* Prof. Forbes and M. Charles Martins concur in showing the same to be the case with a glacier. The observations of both have been objected to; hence it is all the more incumbent on us to seek for decisive evidence.

176. At the Tacul a wall of ice about 150 feet high has already attracted our attention (100). Bending round to join the Léchaud the Glacier du Géant is here drawn away from the mountain side, exposing this fine section. We try to measure it top, bottom, and middle, and are defeated twice over. We try it a third time and succeed. A stake is fixed at the summit of the ice-precipice, another at 4 feet from the bottom, and a third at 35 feet above the bottom. These lower stakes are fixed at the risk of boulders falling upon us from above; but we succeed in measuring the motions of all three. For 24 hours the motions are:—

Top stake	6 inches.
Middle stake	$4\frac{1}{2}$ „
Bottom stake	$2\frac{5}{8}$ „

177. The retarding influence of the bed of the glacier is reduced to demonstration by these measurements. The bottom does not move with half the velocity of the surface.

§ 29.

Sliding and Flowing. Hard Ice and Soft Ice.

178. We have thus far confined ourselves to the measurement and discussion of glacier motion; but in our excursions we have noticed many things besides. Here and there, where the ice has retreated from the mountain side, we have seen the rocks fluted, scored, and polished; thus proving that the ice had slidden over them and ground them down. At the source of the Arveiron we noticed the water rushing from beneath the glacier charged with fine matter. All glacier rivers are similarly charged. The Rhone carries its load of matter into the Lake of Geneva; the rush of the river is here arrested, the matter subsides, and the Rhone quits the lake clear and blue. The Lake of Geneva, and many other Swiss lakes, are in part filled up with this matter, and will, in all probability, finally be obliterated by it.

179. One portion of the motion of a glacier is due to this bodily sliding of the mass over its bed. We have seen in our journeys streams formed by the melting of the ice, and escaping through cracks and *crevasses* to the bed of the glacier. The fine matter

ground down is thus washed away; the bed is kept lubricated, and the sliding of the ice rendered more easy than it would otherwise be.

180. As a skater also you know how much ice is weakened by a thaw. Before it actually melts it becomes rotten and unsafe. Test such ice with your penknife: you can dig the blade readily into it, or cut the ice with ease. Try good sound ice in the same way: you find it much more resistant. The one, indeed, resembles soft chalk; the other hard stone.

181. Now the Mer de Glace in summer is in this thawing condition. Its ice is rendered soft and yielding by the sun; its motion is thereby facilitated. We have seen that not only does the glacier slide over its bed, but that the upper layers slide over the under ones, and that the centre slides past the sides. The softer and more yielding the ice is, the more free will be this motion, and the more readily also will it be forced through a defile like Trélaporte.

182. But in winter the thaw ceases; the quantity of water reaching the bed of the glacier is diminished or cut off. The ice also, to a certain depth at least, is frozen hard. These considerations would justify the opinion that in winter the glacier, if it moves at all, must move more slowly than in summer. At all events, the summer measurements give no clue to the winter motion.

183. I will not ask you to visit the Alps in mid-winter; but, if you allow me, I will be your deputy to the mountains, and report to you faithfully the aspect of the region and the behaviour of the ice.

§ 30.

Winter on the Mer de Glace.

184. The winter chosen is an inclement one. There is snow in London, snow in Paris, snow in Geneva; snow near Chamouni so deep that the road fences are entirely effaced. On Christmas night—nearly at midnight—1859, your deputy reaches Chamouni.

185. The snow fell heavily on the 26th of December; but on the 27th, during a lull in the storm, we turn out. There are with me four good men. They tie planks to their feet to prevent them from sinking in the mass; I neglect this precaution and sink often to the waist. Four or five times during an ascent the snow-slope cracks with an explosive sound, and the snow threatens to come down in avalanches. Four years later, in the spring of 1863, a mighty climber and noble guide, named Johann Joseph Bennen, was lost, through the cracking and subsequent slipping of snow on such a slope. The snow falling during our ascent was in that particular condition when the granules adhere, and hence every flake falling on the trees was retained. The laden pines presented beautiful and often fantastic

forms. Annexed is a sketch of one of them. After five hours and a half of arduous work the Montanvert was attained.

Snow-laden Pine-tree.

186. We unlocked the forsaken auberge, round which the snow was reared in buttresses. I have already spoken of the complex play of crystallizing force. The frost-figures on the window-panes of the auberge were wonderful: mimic shrubs and ferns wrought by the building power while hampered by the adhesion to the glass of the film in which it worked. The appearance of the glacier was very impressive; all sounds were stilled. The cascades which in summer fill the air with their music were silent, hanging from the ledges of the rocks in fluted columns of ice. The surface of the glacier was obviously higher than it had been in summer; suggesting the thought that while the winter cold maintained the lower end of the glacier jammed between its boundaries, the upper portions still moved downwards and thickened the ice. The peak of the Aiguille du Dru shook out a cloud-banner, the origin and nature of which have been already explained (53).

187. On the morning of the 28th this banner was strikingly large and grand, and reddened by the light of the rising sun, it glowed like a flame. Roses of cloud also clustered round the crests of the Grande Jorasse and hung upon the pinnacles of Charmoz. Four men, well roped together, descended to the glacier. I had trained one of them

in 1857, and he was now to fix the stakes. The storm had so distributed the snow as to leave alternate lengths of the glacier bare and thickly covered. Where much snow lay great caution was required, for hidden crevasses were underneath. The men sounded with their staffs at every step. Once while looking at the party through my telescope the leader suddenly disappeared; the roof of a crevasse had given way beneath him; but the other three men promptly gathered round and lifted him out of the fissure. The true line was soon picked up by the theodolite; one by one the stakes were fixed until a series of eleven of them stood across the glacier.

188. To get higher up the valley was impracticable; the snow was too deep, and the aspect of the weather too threatening; so I planted the theodolite amid the pines a little way below the Montanvert, whence through a vista I could see across the glacier. The men were wrapped at intervals by whirling snow-wreaths which quite hid them, and we had to take advantage of the lulls in the wind. Fitfully it came up the valley, darkening the air, catching the snow upon the glacier, and tossing it throughout its entire length into high and violently agitated clouds, separated from each other by cloudless spaces corresponding to the bare portions of the glacier. In the midst of this turmoil the men continued to work. Bravely and steadfastly stake after stake was set, until at length a series of ten of them were fixed across the glacier.

189. Many of the stakes were fixed in the snow. They were four feet in length, and were driven in to a depth of about three feet. But that night while listening to the storm I thought it possible that the stakes and the snow which held them might be carried bodily away before the morning. The storm, however, lulled. We rose with the dawn, but the air was thick with descending snow. It was all composed of those exquisite six-petaled flowers, or six-rayed stars, which have been already figured and described. The weather brightening, the theodolite was planted at the end of the first line. The men descended, and, trained by their previous experience, rapidly executed the measurements. The first line was completed before 11 A.M. Again the snow began to fall, filling all the air. Spangles innumerable were showered upon the heights. Contrary to my expectation, I was able to see the men and direct them through the shower.

190. To reach the position occupied by the theodolite at the end of our second line, I had to wade breast-deep through snow which seemed as dry and soft as flour. The toil of the men in breaking through the glacier snow was prodigious. But they did not flinch, and after a time the leader stood behind the farthest stake, and cried, *Nous avons fini.* I was surprised to hear him so distinctly, for falling snow had been thought very deadening to sound. The work was finished, and I struck my theodolite with the feeling of a general who had won a small battle.

191. We put the house in order, packed up, and shot by glissade down the steep slopes of *La Filia* to the vault of the Arveiron. We found the river feeble, but not dried up. Many weeks must have elapsed since any water had been sent down from the surface of the glacier. But at the setting in of winter the fissures were in a great measure charged with water; and the Arveiron of to-day was probably due to the gradual *drainage* of the glacier. There was now no danger of entering the vault, for the ice seemed as firm as marble. In the cavern we were bathed by blue light. The strange beauty of the place suggested magic, and put me in mind of stories about fairy caves which I had read when a boy. Here our winter visit to the Mer de Glace ends; next morning your deputy was on his way to London.

§ 31.

Winter Motion of the Mer de Glace.

192. Here are the measurements executed in the winter of 1859:—

LINE NO. I.

Stake	1	2	3	4	5	6	7	8	9	10	11
Inches	7	11	14	13	14	14	16	16	12	12	7

LINE NO. II.

Stake	1	2	3	4	5	6	7	8	9	10
Inches	8	10	14	16	16	16	18	17	15	14

193. Thus the winter motion of the Mer de Glace near the Montanvert is, in round numbers, half the summer motion.

194. As in summer, the eastern side of the glacier at this place moved quicker than the western.

§ 32.

Birth of a Crevasse: Reflections.

195. Preserving the notion that we are working together, we will now enter upon a new field of inquiry. We have wrapped up our chain, and are turning homewards after a hard day's work upon the Glacier du Géant, when under our feet, as if coming from the body of the glacier, an explosion is heard. Somewhat startled, we look inquiringly over the ice. The sound is repeated; several shots being fired in quick succession. They seem sometimes to our right, sometimes to our left, giving the impression that the glacier was breaking all round us. Still nothing is to be seen.

196. We closely scan the ice, and after an hour's strict search we discover the cause of the reports. They announce the birth of a crevasse. Through a pool upon the glacier we notice air bubbles ascending, and find the bottom of the pool crossed by a narrow crack, from which the bubbles issue. Right and left from this pool we trace the

young fissure through long distances. It is sometimes almost too feeble to be seen, and at no place is it wide enough to admit a thick knife-blade.

197. It is difficult to believe that the formidable fissures among which you and I have so often trodden with awe, could commence in this small way. Such, however, is the case. The great and gaping chasms on and above the ice-falls of the Géant and the Talèfre begin as narrow cracks, which open gradually to crevasses. We are thus taught in an instructive and impressive way that appearances suggestive of very violent action may really be produced by processes so slow as to require refined observations to detect them. In the production of natural phenomena two things always come into play, the *intensity* of the acting force, and the *time* during which it acts. Make the intensity great, and the time small, and you have sudden convulsion; but precisely the same apparent effect may be produced by making the intensity small, and the time great. This truth is strikingly illustrated by the Alpine ice-falls and crevasses; and many geological phenomena, which at first sight suggest violent convulsion, may be really produced in the self-same almost imperceptible way.

§ 33.

Icicles.

198. Having thus informed ourselves regarding the origin of the crevasses, we will now examine them and classify them. They are grandest on the higher névés, where they sometimes appear as long yawning fissures, and sometimes as chasms of irregular outline. A delicate blue light shimmers from them, but this is gradually lost in the darkness of their profounder portions. Over the edges of the chasms, and mostly over the southern edges, hangs a coping of snow, and from this depend like stalactites rows of transparent icicles 10, 20, 30 feet long. These pendent spears constitute one of the most beautiful features of the higher crevasses.

199. How are they produced? Evidently by the thawing of the snow. But why, when once thawed, should the water freeze again to solid spears? You have seen icicles pendent from a house-eave, which have been manifestly produced by the thawing of the snow upon the roof. If we understand these, we shall also understand the vaster stalactites of the Alpine crevasses.

200. Gathering up such knowledge as we possess, and reflecting upon it patiently, let us found on it, if we can, a theory of icicles.

201. First, then, you are to know that the *air* of our atmosphere is hardly heated at all by the rays of the sun, whether visible or invisible. The air is highly transparent to all kinds of rays, and it is only the scanty fraction to which it is *not* transparent that expend their force in warming it.

202. Not so, however, with the snow on which the sunbeams fall. It absorbs the solar heat, and on a sunny day you may see the summits of the high Alps glistening with the water of liquefaction. The *air* above and around the mountains may at the same time be many degrees below the freezing point in temperature.

203. You have only to pass from sunshine into shade to prove this. A single step suffices to carry you from a place where the thermometer stands high to one where it stands low; the change being due, not to any difference in the temperature of the *air*, but simply to the withdrawal of the thermometer from the direct action of the solar rays. Nay, without shifting the thermometer at all, by interposing a suitable screen, which cuts off the sun's rays, the cold of the air may be demonstrated.

204. Look now to the snow upon your house roof. The sun plays upon it, and melts it; the water trickles to the eave and then drops down. If the eave face the sun the water remains water; but if the eave do not face the sun, the drop, before it quits its parent snow, *is already in shadow.* Now the shaded space, as we have learnt, may be below the freezing temperature. If so, the drop, instead of falling, congeals, and the rudiment of an icicle is thus formed. Other drops and driblets succeed, which trickle over the rudiment, congeal upon it in part and *thicken* it at the root. But a portion of the water reaches the free end of the icicle, hangs from it, and is there congealed before it escapes. The icicle is thus *lengthened.* Here, I think, we have the secret of our Alpine stalactites. In the Alps, however, where the liquefaction is copious and the cold of the shaded crevasse intense, the icicles, though produced in the same way, naturally grow to a vaster size.

205. It is interesting and important that you should be able to explain the formation of an icicle; but it is far more important that you should realize the way in which the various threads of what we call Nature are woven together. You cannot fully understand an icicle without first knowing that solar beams powerful enough to fuse the snows and blister the human skin, nay, it might be added, powerful enough, when concentrated, to burn up the human body itself, may pass through the air, and still leave it at an icy temperature.

§ 34.

Crevasses. The Bergschrund.

206. Having cleared away this difficulty, let us turn once more to our crevasses, taking them in the order of their formation. First then above the névé we have the final Alpine peaks and crests, against which the snow is often reared as a steep buttress. We have already learned that both névés and glaciers are moving slowly downwards; but it usually happens that the attachment of the highest portion of the buttress to the rocks is great enough to enable it to hold on while

the lower portion breaks away. A very characteristic crevasse is thus formed, called in the German-speaking portion of the Alps a *Bergschrund*. It often surrounds a peak like a fosse, as if to defend it against the assaults of climbers.

207. Look more closely into its formation. Imagine the snow as yet unbroken. Its higher portions cling to the rocks, and move downwards with extreme slowness. But its lower portions, whether from their greater depth and weight, or their less perfect attachment, are compelled to move more quickly. *A pull* is therefore exerted tending to separate the lower from the upper snow. For a time this pull is resisted by the cohesion of the névé; but this at length gives way, and a crack is formed exactly *across* the line in which the pull is exerted. In other words, *a crevasse is formed at right angles to the line of tension.*

§ 35.

Transverse Crevasses.

208. Both on the névé and on the glacier the origin of the crevasses is the same. Through some cause or other the ice is thrown into a state of strain, and as it cannot *stretch* it *breaks* across the line of tension. Take, for example, the ice-fall of the Géant, or of the Talèfre, above which you know the crevasses yawn terribly. Imagine the névé and the glacier entirely peeled away, so as to expose the surface over which they move. From the Col du Géant we should see this surface falling gently to the place now occupied by the brow of the cascade. Here the surface would fall steeply down to the bed of the present Glacier du Géant, where the slope would become gentle once more.

209. Think of the névé moving over such a surface. It descends from the Col till it reaches the brow just referred to. It crosses the brow, and must bend down to keep upon its bed. Realize clearly what must occur. The surface of the névé is evidently thrown into a state of strain; it breaks and forms a crevasse. Each fresh portion of the névé as it passes the brow is similarly broken, and thus a succession of crevasses is sent down the fall. Between every two chasms is a great transverse ridge. Through local strains upon the fall those ridges are also frequently broken across, towers of ice—*séracs*—being the result. Down the fall both ridges and séracs are borne, the dislocation being augmented during the descent.

210. What must occur at the foot of the fall? Here the slope suddenly lessens in steepness. It is plain that the crevasses must not only cease to open here, but that they must in whole or in part close up. At the summit of the fall, the bending was such as to make the surface convex; at the bottom of the fall the bending renders the surface concave. In the one case we have *strain*, in the other *pressure*. In the one case, therefore, we have the *opening*, and in the other

the *closing* of crevasses. This reasoning corresponds exactly with the facts of observation.

211. Lay bare your arm and stretch it straight. Make two ink dots half an inch or an inch apart, exactly opposite the elbow. Bend your arm, the dots approach each other, and are finally brought together. Let the two dots represent the two sides of a crevasse at the bottom of an ice-fall; the bending of the arm resembles the bending of the ice, and the closure of the fissures is a consequence of this bending.

212. The same remarks apply to various portions of the Mér de Glace. At certain places the inclination changes from a gentler to a steeper slope, and on crossing the brow between both the glacier breaks its back. *Transverse crevasses* are thus formed. There is such a change of inclination opposite to the angle, and a still greater similar change at the head of the Glacier des Bois. The consequence is that the Mer de Glace at the former point is impassable, and in the latter the rending and dislocation are such as we have seen and described. Below the angle, and at the bottom of the Glacier des Bois, the steepness relaxes, the crevasses heal up, and the glacier becomes once more continuous and compact.

§ 36.

Marginal Crevasses.

213. Supposing, then, that we had no changes of inclination, should we have no crevasses? We should certainly have less of them, but they would not wholly disappear. For other circumstances exist to throw the ice into a state of strain, and to determine its fracture. The principal of these is the more rapid movement of the centre of the glacier.

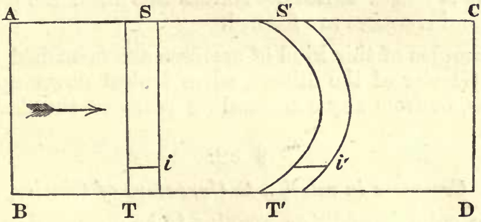
214. Helped by the labours of an eminent man, now dead, the late Mr. Wm. Hopkins, of Cambridge, let us master the explanation of this point together. But the pleasure of mastering it would be enhanced if we could see beforehand the perplexing and delusive appearances accounted for by the explanation. Could I follow out my wishes, I would at this point of our researches carry you off with me to Basel, thence to Thun, thence to Interlaken, thence to Grindelwald, where you would find yourself in the actual presence of the Wetterhorn and the Eiger, with all the greatest peaks of the Bernese Oberland, the Finsteraarhorn, the Schreckhorn, the Monch, the Jungfrau, at hand. At Grindelwald there are two well-known glaciers—the Ober Grindelwald and the Unter Grindelwald glaciers—on the latter of which our observations should commence.

215. Dropping down from the village to the bottom of the valley we should breast the opposite mountain, and with the great limestone precipices of the Wetterhorn to our left, we should get upon a path which commands a view of the glacier. Here we should see beautiful

examples of the opening of crevasses at the summit of a brow, and their closing at the bottom. But the chief point of interest would be the crevasses formed at the *side* of this glacier—the *marginal crevasses*, as they may be called.

216. We should find the side copiously fissured, even at those places where the centre is compact; and we should particularly notice that the fissures would neither run in the direction of the glacier, nor straight across it, but that they would be *oblique* to it, enclosing an angle of about 45 degrees with the sides. Starting from the side of the glacier the crevasses would be seen to point *upwards;* that is to say, the ends of the fissures abutting against the bounding mountain would appear to be *dragged down.* Were you less instructed than you now are, I might lay a wager that the aspect of these fissures would cause you to conclude that the centre of the glacier is left behind by the quicker motion of the sides.

217. This indeed was the conclusion drawn by M. Agassiz from this very appearance before he had measured the motion of the sides and centre of the glacier of the Unteraar. Intimately versed with the treatment of mechanical problems, Mr. Hopkins immediately deduced the obliquity of the lateral crevasses from the quicker flow of the centre. Standing beside the glacier with my pencil and note-book in my hand, I will at once make the matter clear to you.



218. Let A C, in the annexed figure, be one side of the glacier, and B D the other. The line A B being higher up than C D: the direction of motion would then be indicated by the arrow. Let S T be a transverse slice of the glacier, taken straight across it, say to-day. A few days or weeks hence this slice will have been carried down, and because the centre moves more quickly than the sides it will not remain straight but will bend into the form S′ T′.

219. Supposing T *i* to be a small square of the original slice near the side of the glacier. In its new position the square will be distorted to the lozenge-shaped figure T′ *i*′. Fix your attention upon the diagonal T *i* of the square; in the lower position this diagonal, *if the ice could stretch*, would be lengthened to T′ *i*′. But the ice does not stretch; it breaks, and we have a crevasse formed at right angles to T′ *i*′. The mere inspection of the diagram will assure you that the crevasse will point obliquely *upwards*.

220. Along the whole side of the glacier the quicker movement of the centre produces a similar state of strain; and the consequence is that the side is copiously fissured even at places where the centre is free from crevasses.

221. It is curious to see at other places the transverse fissures of the centre uniting with those at the sides, so as to form great curved crevasses which stretch across the glacier from side to side. The convexity of the curve is turned upwards, as mechanical principles declare it ought to be. But if you were ignorant of those principles you would never infer from the aspect of these curved crevasses the quicker motion of the centre. In landslips, and in the motion of partially indurated mud, you may sometimes notice appearances similar to those exhibited by the ice.

§ 37.

Longitudinal Crevasses.

222. We have thus unravelled the origin of both transverse and marginal crevasses. But where a glacier issues from a steep and narrow defile upon a comparatively level plain which allows it room to expand laterally, its motion is in part arrested, and the level portion has to bear the thrust of the steeper portions behind. Here the line of thrust is in the direction of the glacier, while the direction at right angles to this is one of tension. Across this latter the glacier breaks, and *longitudinal crevasses* are formed.

223. Examples of this kind of crevasse are furnished by the lower part of the Glacier of the Rhone, when looked down upon from the Grimsel Pass, or from any commanding point on the flanking mountains.

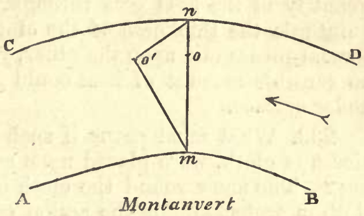
§ 38.

Crevasses in relation to Curvature of Glacier.

224. One point in addition remains to be discussed, and your present knowledge will enable you to master it in a moment. You remember at an early period of our researches that we crossed the Mer de Glace from the Chapeau side to the Montanvert side. I then desired you to notice that the Chapeau side of the glacier was more fissured than either the centre or the Montanvert side (75). Why should this be so? Knowing as we now do that the Chapeau side of the glacier moves more quickly than the other; that the point of maximum motion does not lie on the centre but far east of it, we are prepared to answer this question in a perfectly satisfactory manner.

225. Let A B and C D, in the annexed diagram, represent the two curved sides of the Mer de Glace at the Montanvert, and let *m n* be a straight line across the glacier. Let *o* be the point of maximum motion. The mechanical state of the two sides of the glacier may, I think, be thus made plain. Supposing the line *m n* to be a straight elastic string with its ends fixed; let it be grasped firmly at the point *o* by the

finger and thumb, and drawn to o', keeping the distance between o' and the side C D constant. Here the length, $n o$ of the string would have stretched to $n o'$, and the length $m o$ to $m o'$, and you see plainly that the stretching of the short line, in comparison with its length, is greater than that of the long line in comparison with its length. In other words, the strain upon $n o'$ is greater than that upon $m o'$; so that if one of them were to break under the strain it would be the short one.



226. These two lines represent the conditions of strain upon the two sides of the glacier. The sides are held back, and the centre tries to move on, a strain being then set up between the centre and sides. But the displacement of the point of maximum motion through the curvature of the valley makes the strain upon the eastern ice greater than that upon the western. The eastern side of the glacier is therefore more crevassed than the western.

227. Here indeed resides the difficulty of getting along the eastern side of the Mer de Glace, a difficulty which was one reason for our crossing the glacier opposite to the Montanvert. There are two convex sweeps on the eastern side to one on the western side, hence on the whole the eastern side of the Mer de Glace is most riven.

§ 39.

Moraine-ridges, Glacier Tables, and Sand-Cones.

228. When you and I first crossed the Mer de Glace from Trélaporte to the Couvercle, we found that the stripes of rocks and rubbish which constituted the medial moraines were ridges raised above the general level of the glacier to a height at some places of twenty or thirty feet. On examining these ridges we found the rubbish to be superficial, and that it rested upon a great spine of ice which ran along the back of the glacier. By what means has this ridge of ice been raised?

229. Most boys have read the story of Dr. Franklin's placing bits of cloth of various colours upon snow on a sunny day. The bits of cloth sank in the snow, the dark ones most.

230. Consider this experiment. The sun's rays first of all fall upon the upper surface of the cloth and warm it. The heat is then conducted through the cloth to the under-surface, and the under-surface passes it on to the snow which is liquefied by it. It is quite manifest that the quantity of snow melted will altogether depend upon the amount of heat sent from the upper to the under surface of the cloth.

231. Now cloth is what is called a bad conductor of heat. It does not permit heat to travel freely through it. But where the heat has merely to pass through the thickness of a single bit of cloth, a good quantity of the heat gets through. But if you double or treble or quintuple the thickness of the cloth; or, what is easier, if you put several pieces one upon the other, you come at length to a point where no sensible amount of heat could get through from the upper to the under surface.

232. What must occur if such a thick piece, or such a series of pieces of cloth, were placed upon snow on which a strong sun is falling? The snow round the cloth is melted, but that underneath the cloth is protected. If the action continue long enough the inevitable result will be that the level of the snow all round the cloth will sink, and the cloth will be left behind perched upon an eminence of snow.

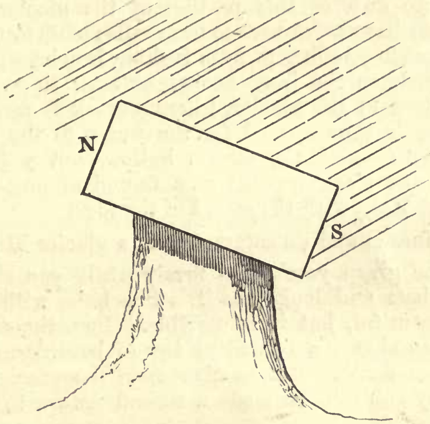
233. If you understand this you have already mastered the cause of the moraine-ridges. They are produced by no swelling of the ice upwards. But the ice underneath the rocks and rubbish being protected from the sun, the glacier right and left melts away and leaves a ridge behind.

234. Various other appearances upon the glacier are accounted for in the same way. Here upon the Mer de Glace we have flat slabs of rock sometimes lifted up on pillars of ice. These are the so-called *Glacier Tables.* They are produced, not by the growth of a stalk of ice out of the glacier, but by the melting of the glacier all round the ice protected by the stone. Annexed is a sketch of one of the Tables of the Mer de Glace.

235. Notice that a glacier table is hardly ever set square upon its stalk. It generally leans to one side, and repeated observation

teaches you that it so leans as to enable you always to draw the north and south line upon the glacier. For the sun being south of the zenith pours its rays against the southern end of the table, while the northern end remains in shadow. The southern end, therefore, being most warmed does not protect the ice underneath it so effectually as the northern end. The table becomes inclined, and ends by sliding bodily off its pedestal.

236. Here is what may be called an ideal table. The oblique lines represent the direction of the sunbeams, and the consequent tilting of the table here shown resembles that observed upon the glaciers.



237. A pebble will not rise thus :—like Franklin's single bit of cloth, a dark-coloured pebble sinks in the ice. A spot of black mould will not rest upon the surface but will sink; and various parts of the Glacier du Géant are honeycombed by the sinking of such spots of dirt into the ice.

238. But when the dirt is of a thickness sufficient to protect the ice the case is different. Sand is often washed away by a stream from the mountains, or from the moraines, and strewn over certain spaces of the glacier. A most curious action follows : the sanded surface rises, the part on which the sand lies thickest rising highest. Little peaks and eminences jut forth, and when the distribution of the sand is favourable, and the action sufficiently prolonged, you have little mountains formed, sometimes singly, and sometimes grouped so as to mimic the Alps themselves. The *Sand Cones* of the Mer de Glace are not striking ; but on the Görner, the Aletsch, the Morteratsch, and other glaciers, they reach sometimes a height of ten or twenty feet.

§ 40.

The Glacier Mills or Moulins.

239. You and I have learned by long experience the character of the Mer de Glace. We have marched over it daily, with a definite object in view, but we have not closed our eyes to other objects. It is from side glimpses of things which are not at the moment occupying our attention that fresh subjects of inquiry arise in scientific investigation.

240. Thus in marching over the ice near Trélaporte we were often struck by a sound resembling low rumbling thunder. We subsequently sought out the origin of this sound and found it.

241. A large area of this portion of the glacier is unbroken. Driblets of water have room here to form rills; rills to unite and form streams; streams to combine to form rushing brooks, which sometimes cut deep channels in the ice. Sooner or later these streams reach a strained portion of the glacier, where a crack is formed across the stream. A way is thus opened for the water to the bottom of the glacier. By long action the stream hollows out a shaft, the crack thus becoming the starting-point of a funnel of unseen depth, into which the water leaps with the sound of thunder.

242. This funnel and its cataract form a glacier Mill or *Moulin.*

243. Let me grasp your hand firmly while you stand upon the edge of this shaft and look into it. The hole, with its pure blue shimmer, is beautiful, but it is terrible. Incautious persons have fallen into these shafts, a second or two of bewilderment being followed by sudden death. But caution upon the glaciers and mountains ought, by habit, to be made a second nature to explorers like you and me.

244. The crack into which the stream first descended to form the moulin, moves down with the glacier. A succeeding portion of the ice reaches the place where the breaking strain is exerted. A new crack is then formed above the moulin, which is thenceforth forsaken by the stream, and moves downward as an empty shaft. Here upon the Mer de Glace, in advance of the *Grand Moulin*, we see no less than six of these forsaken holes. Some of them we sound to a depth of 90 feet.

245. But you and I both wish to determine, if possible, the entire depth of the Mer de Glace. The Grand Moulin offers a chance of doing this which we must not neglect. Our first effort to sound the moulin fails through the breaking of our cord by the impetuous plunge of the water. A lump of grease in the hollow bottom of a weight enables a mariner to judge of a sea bottom. We employ such a weight, but cannot reach the bottom of the glacier. A depth of 163 feet is the utmost reached by our plummet.

246. From the 28th of July to the 8th of August the progress of

the Grand Moulin has been watched. On the former date the position of the Moulin was fixed. On the 31st it had moved down 50 inches; a little more than a day afterwards it had moved 74 inches. On the 8th of August it had moved 198 inches, which amounts to about 18 inches in twenty-four hours. No doubt next summer upon the Mer de Glace a Grand Moulin will be found thundering near Trélaporte; but like the crevasse of the Grand Plateau already referred to, it will not be our Moulin. This, or rather the ice which it penetrated, is now probably more than a mile lower down than it was in 1857.

§ 41.

Sea-ice and Icebergs.

247. We are now equipped intellectually for a campaign into another territory. Water becomes heavier when salt is dissolved in it, and more difficult to freeze. Sea water is therefore heavier than fresh, and the Greenland Ocean requires to freeze it a temperature $3\frac{1}{2}$ degrees lower than fresh water. When concentrated till its specific gravity reaches $1 \cdot 1045$, sea water requires for its congelation a temperature $18\frac{1}{3}$ degrees lower than the ordinary freezing-point.*

248. But even when the water is saturated with salt, the crystallizing force studiously rejects the salt, and devotes itself to the congelation of the water alone. Hence the ice of sea water, when melted, produces fresh water. The only saline particles existing in such ice are those entangled mechanically in its pores. They have no part or lot in the structure of the crystal.

249. This *exclusiveness*, if I may use the term, of the water molecules; this entire rejection of all foreign elements from the edifices which they build, is enforced to a surprising degree. Sulphuric acid has so strong an affinity for water that it is one of the most powerful agents known to the chemist for the removal of humidity from air. Still, as shown by Faraday, when a mixture of sulphuric acid and water is frozen, the crystal formed is perfectly sweet and free from acidity. The water alone has lent itself to the crystallizing force.

250. Every winter in the Arctic regions the sea freezes, roofing itself with ice of enormous thickness and vast extent. By the summer heat, and the tossing of the waves, this is broken up; the fragments are drifted by winds and borne by currents. They clash, they crush each other, they pile themselves into heaps, thus constituting the chief danger encountered by mariners in the polar seas.

251. But among the drifting masses of flat sea-ice, vaster masses sail, which spring from a totally different source. These are the *Icebergs* of the Arctic seas. They rise sometimes to an elevation of hundreds of feet above the water, while the weight of ice submerged is about seven times that seen above.

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* Scoresby.

252. The first observers of striking natural phenomena generally allow wonder and imagination more than their due place. But to exclude all error arising from this cause, I will refer to the journal of a cool and intrepid Arctic navigator, Sir Leopold McClintock. He describes an iceberg 250 feet high, which was aground in 500 feet of water. This would make the entire height of the Berg 750 feet, not an unusual altitude for the greater icebergs.

253. From Baffin's Bay these mighty masses come sailing down through Davis' Straits into the broad Atlantic. A vast amount of heat is demanded for the simple liquefaction of ice; and the melting of icebergs is on this account so slow, that when large they sometimes maintain themselves till they have been drifted 2000 miles from their place of birth.

254. What is their origin? The Arctic glaciers. From the mountains in the interior the indurated snows slide into the valleys and charge them with ice. The glaciers thus formed move like the Swiss ones, incessantly downward. But the Arctic glaciers reach the sea, enter it, often ploughing up its bottom into submarine moraines. Undermined by the lapping of the waves, and unable to resist the strain imposed by their own weight, they break across, and discharge vast masses into the ocean. Some of these run aground on the adjacent shores, and often maintain themselves for years. Others escape southward to be finally dissolved in the warm waters of the Atlantic. I shall have occasion to show you pictures of some extraordinary icebergs photographed during a recent expedition by Mr. Bradford to the Northern seas.

§ 42.

The Märgelin See and its Icebergs.

255. I am, however, unwilling that you should quit Switzerland without seeing such icebergs as it can show, and indeed there are other nobler glaciers than the Mer de Glace with which you ought to be acquainted. In tracing the Rhone to its source, you have already ascended the valley of the Rhone. Let us visit it again together; halt at the little town of Viesch, and go from it straight up to the excellent hostelry on the slope of the Æggischhorn. This we shall make our head-quarters while we explore that monarch of European ice-streams,—the great Aletsch glacier.

256. Including the longest of its branches, this noble ice-river is about 20 miles long, while at the middle of its trunk it measures nearly a mile and a quarter from side to side. The grandest mountains of the Bernese Oberland, the Jungfrau, the Monch, the Trugberg, the Aletschhorn, the Breithorn, the Gletscherhorn, and many another noble peak and ridge, are the collectors of its *névés*. From three great valleys formed in the heart of the mountains these névés are poured, uniting together to form the trunk of the Aletsch at a place named

by a witty mountaineer the "Place de la Concorde of Nature." If the phrase be meant to convey the ideas of tranquil grandeur, beauty of form, and purity of hue, it is well bestowed.

257. Our hotel is not upon the peak of the Æggischhorn, but a brisk morning walk soon places us upon the top. Thence we see the glacier like a broad river stretching upwards to the roots of the Jungfrau, and downwards past the Bel Alp towards its end. Prolonging the vision downwards, we strike the noblest mountain group in all the Alps,—the Dom and its attendant peaks, the Matterhorn and the Weisshorn. The scene indeed is one of impressive grandeur, a multitude of peaks and crests here unnamed contributing to its glory.

258. But low down to our right, and surrounded by the sheltering mountains, is an object the beauty of which startles those who are unprepared for it. Yonder we see the naked side of the glacier, exposing glistening ice-cliffs 60 or 70 feet high. It would seem as if the Aletsch here were engaged in the vain attempt to thrust an arm through a lateral valley. It once did so; but the arm is now incessantly broken off close to the body of the glacier, a great space formerly covered by the ice being now occupied by its water of liquefaction. A lake of the loveliest blue is thus formed, which reaches quite to the base of the ice-cliffs, saps them, as the Arctic waves sap the Greenland glaciers, and receives from them the broken masses which it has undermined. As we look down upon the lake, small icebergs sail over the tranquil surface, each resembling a snowy swan accompanied by its shadow.

259. This is the beautiful little lake of Märgelin, or, as the Swiss here call it, the Märgelin See. You see that splash, and immediately afterwards hear the sound of the plunging ice. The glacier has broken before our eyes and dropped an iceberg into the lake. All over the lake the water is set in commotion, thus illustrating on a small scale the swamping waves produced by the descent of vast islands of ice from the Arctic glaciers. Look to the end of the lake. It is cumbered with the remnants of icebergs now aground, which have been in part wafted thither by the wind, but in part slowly borne by the water which moves gently in this direction.

260. Imagine us below upon the margin of the lake, as I happened to be on one occasion. There is one large and lonely iceberg about the middle. Suddenly a sound like that of a cataract is heard; we look towards the iceberg and see water teeming from its sides. Whence comes the water? the berg has become top-heavy through the melting underneath; it is in the act of performing a somersault, and in rolling over carries with it a vast quantity of water, which rushes like a waterfall down its sides. And notice that the iceberg, which a moment ago was snowy-white, now exhibits the delicate blue colour characteristic of compact ice. It will soon, however, be rendered white again by the action of the sun. The vaster icebergs of the northern seas sometimes roll over in the same fashion.

§ 43.

Motion of the Aletsch Glacier.

261. While here we will dwell for a moment on the motion of the great Aletsch glacier, as measured by Mr. Vaughan Hawkins and myself in 1860. The theodolite was planted high among the rocks on the western flank of the mountain, about half a mile above the Märgelin See. Here, on the 14th of August, thirty-four stakes were fixed in a straight line across the glacier. The displacement of these stakes was measured on the 16th. Reduced to its daily rate the motion was as follows:—

Motion of Great Aletsch Glacier.

	East.											
Stake	1	2	3	4	5	6	7	8	9	10	11	12
Inches.....	2	3	4	6	8	11	13	14	16	17	17	19
Stake	13	14	15	16	17	18	19	20	21	22	23	
Inches.....	19	18	18	17	19	19	19	19	17	17	15	
Stake	24	25	26	27	28	29	30	31	32	33	34	
Inches.....	16	17	17	17	17	17		17	16	12	12	
											West.	

262. The maximum motion here is 19 inches a day. Probably the eastern side of the glacier here is shallow, the retardation of the bed making the motion of the eastern stakes inconsiderable.

263. The width of the glacier here was 9030 links, or about a mile and a furlong.

§ 44.

Ancient Glaciers of Switzerland.

264. You have not lost the memory of the old Moraine, which interested us so much in our first ascent from the source of the Arveiron; for it opened our minds to the fact that at one period of its history the Mer de Glace attained far greater dimensions than it now exhibits. Our experience since that time has enabled us to pursue these evidences of ice action to an extent of which we had then no notion.

265. Close to the existing glacier, for example, we have repeatedly seen the mountain side laid bare by the retreat of the ice. This is especially conspicuous just now, because for the last fifteen or sixteen years the glaciers of the Alps have been steadily shrinking; so that it is no uncommon thing to see the marginal rocks laid bare for a height of 50, 60, 80, or even 100 feet above the present glacier. On the rocks thus exposed we see the evident marks of the sliding; and our eyes and minds have been so educated in the observation of these appearances that we are now able to detect, with certainty, ice-marks, ancient or modern, wherever they appear.

266. But the elevations at which we have found such markings

might well shake belief in the conclusions to which they point. I will carry you to a region which exhibits them on a grander and more impressive scale than the Mer de Glace. We have already taken a brief flight to the valley of Hasli and the Glacier of the Aar. Let us make that glacier our starting-point. Walking from it downwards towards the Grimsel we pass everywhere over rocks singularly rounded, and fluted, and scarred. These appearances are manifestly the work of the glacier in recent times. But we approach the Grimsel, and at the turning of the valley stand before the precipitous granite flank of the mountain. The traces of the ancient ice are here as plain as they are amazing. The rocks are so hard that not only the fluting and polishing, but even the fine scratches which date back unnamable thousands of years are as evident as if they had been made yesterday. We may trace these evidences to a height of fully two thousand feet above the present valley bed. It is indubitable that an ice-river of this astounding depth once flowed through the vale of Hasli.

267. Yonder is the summit of the Siedelhorn; and if we gain it, the Unteraar glacier will be like a map below us. From this commanding point we plainly see marked upon the mountain sides the height to which the ancient ice extended. The ice-ground part of the mountains is clearly distinguished from the splintered crests which in those distant days rose above the surface of the glacier, and which must have then appeared as island peaks and crests in the midst of an ocean of ice.

268. We now scamper down the Siedelhorn, get once more into the valley of Hasli, along which we follow for a score of miles the traces of the ice. Fluted precipices, polished slabs, and beautifully-rounded granite domes. Right and left upon the mountain flanks, at great elevations, the evidences also appear. We follow the footsteps of the glacier to the Lake of Brientz, and if we prolonged our inquiries we should learn that all the lake beds of this region, at the time now referred to bore the burden of immense masses of ice.

269. Instead of the vale of Hasli we might take the valley of the Rhone. The traces of a mighty glacier, which formerly filled it, may be followed all the way to Martigny, which is 60 miles distant from the present ice. At Martigny the Rhone glacier was reinforced by another from Mont Blanc, and the welded masses moved onward, planing the mountains right and left, to the Lake of Geneva, the bed of which they entirely filled. Other evidences prove that the glacier did not end here, but pushed across the low country until it encountered the limestone barrier of the Jura mountains.

§ 45.

Erratic Blocks.

270. What are these other evidences? We have seen mighty rocks poised on the moraines of the Mer de Glace, and we now know

that unless they are split and shattered by the frost these rocks will, at some distant day, be landed by the Glacier des Bois in the valley of Chamouni. You have already learned that these boulders often reveal the mineralogical nature of the mountains among which the glacier has passed; that specimens are thus brought down of a character totally different from the rocks among which they are finally landed; this is strikingly the case with the *erratic blocks* stranded along the Jura.

271. For the Jura itself, as already stated, is limestone; there is no trace of native granite to be found amongst these hills. Still along the breast of the mountain above the town of Neufchatel, and at about 800 feet above the lake of Neufchatel, we find stranded a belt of granite boulders from Mont Blanc. And when we clear the soil away from the adjacent mountain side we find the scarrings of the ancient glacier which landed the boulders here.

272. The most famous of these rocks, called the Pierre à Bôt, measures 50 feet in length, 40 in height, and 20 in width. Multiplying these three numbers together, we obtain 40,000 cubic feet as the volume of the boulder.

273. But even this is small compared to some of the rocks which constitute the freight of even recent glaciers. Let us visit another of them. From the town of Visp in the valley of the Rhone we walk southwards to Stalden. Here the valley divides into two branches, the right branch running to St. Nicolas and Zermatt, and the left one to Saas and the Monte Moro. Three hours above Saas we come upon the end of the Allelein glacier, not filling the main valley, but thrown athwart it so as to stop its drainage like a dam. Above this ice-dam we have the Mattmark Lake, and at the head of the lake a small inn well known to travellers over the Monte Moro.

274. Close to this inn is the greatest glacial boulder that we have ever seen. It measures 240,000 cubic feet. Looking across the valley we notice a glacier with its present end half a mile from the boulder. The stone I believe is serpentine, and were you and I to explore the Schwartzberg glacier to its upper fastnesses, we should find among them the birthplace of this gigantic stone. Four-and-forty years ago, when the glacier reached the place now occupied by the boulder, it landed there its mighty freight, and then retreated. There is a second boulder at hand which would be considered vast were it not dwarfed by the aspect of its huger neighbour.

275. Evidence of this kind might be multiplied to any extent. In fact, at this moment, distinguished men like Professor Favre, of Geneva, are determining from the distribution of the erratic blocks the extent of the ancient glaciers of Switzerland. It was, however, an engineer named Venetz that first brought these evidences to light, and announced to an incredulous world the vast extension of the

ancient ice. M. Agassiz afterwards developed and wonderfully expanded the discovery.

§ 46.

Ancient Glaciers of England, Ireland, Scotland, and Wales.

276. At the time the ice attained this extraordinary development in the Alps, many other portions of Europe, where no glaciers now exist, were covered with them. In the Highlands of Scotland, among the mountains of England, Ireland and Wales, the ancient glaciers have written their story as plainly as in the Alps themselves. I should like to wander with you through Borrodale in Cumberland, or through the valleys near Bethgellert in Wales. Under all the beauty of the present scenery we should discover the memorials of a time when the whole region was locked in the embrace of ice. Dr. Hooker found the cedars of Lebanon growing on ancient moraines.

277. We have made the acquaintance of the Reeks of Magillicuddy as the great condensers of Atlantic vapour. At the time now referred to, this moisture did not fall as soft and fructifying rain, but as snow, which formed the nutriment of great glaciers. A chain of lakes now constitutes the chief attraction of Killarney, the Lower, the Middle, and the Upper Lake. Let us suppose ourselves rowing towards the head of the Upper Lake with the Purple Mountain to our right. Remembering our travels in the Alps, you would infallibly call my attention to the planing of the rocks, and declare the action to be unmistakably that of glaciers. With our attention thus sharpened, we land at the head of the Lake, and walk up the Black Valley to the base of Magillicuddy's Reeks. Your conclusion would be that this valley tells a tale as wonderful as that of Hasli.

278. We reach our boat and row homewards along the Upper Lake. Its islands now possess a new interest for us. Some of them are bare, others are covered wholly or in part with luxuriant vegetation; but both the naked and clothed islands are all glaciated. The rains of ages have not altered their forms: there are the Cannon Rock, the Giant's Coffin, the Man of War, all sculptured as if the chisel had passed over them in our own lifetime. These lakes, now fringed with tender woodland beauty, were all occupied by the ancient ice. It has disappeared, and seeds from other regions have been wafted thither to sow the trees, the shrubs, the ferns, and the grasses which now beautify Killarney. Man himself, they say, has made his appearance in the world since that time of ice, but of the real period of man's introduction philosophers seem to know but little.

279. It is the nature and tendency of the human mind to look backward and forward; to endeavour to restore the past and predict the future. Thus endowed, from data patiently and painfully won, we recover in idea a state of things which existed thousands, it may be millions of years, before the history of the human race began.

§ 47.

The Glacial Epoch.

280. This period of ice-extension has been named the *Glacial Epoch.* In accounting for it great minds have fallen into grave errors, as we shall presently see.

281. The substance on which we have thus far been working exists in three different states; as a solid in ice; as a liquid in water; as a gas in vapour. To cause it to pass from one of these states to the next following one, heat is necessary.

282. Dig a hole in the ice of the Mer de Glace in summer, and place a thermometer in the hole: it will stand at 32° Fahr. Dip your thermometer into one of the glacier streams; it will still mark 32°. *The water is therefore as cold as the ice.*

283. Hence the whole of the heat poured by the sun upon the glacier, and which has been absorbed by the glacier, is expended in simply liquefying the ice, and not in rendering either ice or water a single degree warmer.

284. Expose water to a fire; it becomes hotter for a time. It boils, and from that moment it ceases to get hotter. After it has begun to boil, all the heat communicated by the fire is carried away by the steam, *though the steam itself is not the least fraction of a degree hotter than the water.*

285. In fact, simply to liquefy ice a large quantity of heat is necessary, and to vaporize water a large quantity is also necessary. And inasmuch as this heat does not render the water warmer than the ice, nor the steam warmer than the water, it was supposed to be *hidden* in the water and in the steam. And it was therefore called *latent heat.*

286. We are now only concerned with the latent heat of vapour. Let us ask how much heat must the sun expend in order to convert a pound weight of the tropical ocean into vapour? This problem has been accurately solved by experiment. It would require in round numbers 1000 times the amount of heat necessary to raise 1 lb. of water one degree in temperature.

287. But the quantity of heat which would raise the temperature of a pound of water one degree would raise the temperature of a pound of iron *ten* degrees. This has been also proved by experiment. Hence to convert one pound of the tropical ocean into vapour the sun must expend 10,000 times as much heat as would raise 1 lb. of iron one degree in temperature.

288. This quantity of heat would raise the temperature of 5 lbs. of iron 2000 degrees, which is the fusing point of cast iron; at this temperature the metal would not only be *white hot,* but would be passing into the molten condition.

289. Consider the conclusions at which we have now arrived. For every pound of tropical vapour, or for every pound of Alpine ice produced by the congelation of that vapour, an amount of heat has been expended by the sun sufficient to raise 5 lbs. of cast iron to its melting-point.

290. It would not be difficult to calculate approximately the weight of the Mer de Glace and its tributaries—to say, for example, that they contained so many millions of millions of tons of ice and snow. Let the place of the ice be taken by a mass of white-hot iron of quintuple the weight; with such a picture before your mind you get some notion of the enormous amount of heat paid out by the sun to produce the present glacier.

291. You must think over this, until it is as clear as sunshine. For you must never henceforth fall into the error already referred to, and which has entangled so many. So natural was the association of ice and cold, that even celebrated men assumed that all that is needed to produce a great extension of our glaciers is a diminution of the sun's temperature. Had they gone through the foregoing reflections and calculations, they would probably have demanded *more* heat instead of less for the production of a "glacial epoch." What they really needed were *condensers* sufficiently powerful to congeal the vapour generated by the heat of the sun.

§ 48.

Glacier Theories.

292. You have not forgotten, and hardly ever can forget, our climbs to the Cleft Station. Thoughts were there suggested which we have not yet discussed. We saw the branch glaciers coming down from their névés, welding themselves together, pushing through Trélaporte, and afterwards moving through the sinuous valley of the Mer de Glace. These appearances alone, without taking into account subsequent observations, were sufficient to suggest the idea that glacier ice, however hard and brittle it may appear, is really a viscous substance, resembling treacle, or honey, or tar, or lava.

§ 49.

Dilatation and Sliding Theories.

293. Still this was not the notion expressed by the majority of writers upon glaciers. Scheuchzer of Zurich, a great naturalist, visited ice-glaciers in 1705, and propounded a theory of their motion. Water, he knew, expands in freezing, and the force of expansion is so great, that thick bombshells filled with water and permitted to freeze are shattered to pieces by the ice within. Scheuchzer supposed that the water in the fissures of the glaciers, freezing there and expanding with resistless force, was the power which urged the glacier down-

wards. He added to this theory other notions of a less scientific kind.

294. Many years subsequently, De Charpentier of Bex renewed and developed this theory with such ability and completeness, that it was long known as Charpentier's Theory of Dilatation. M. Agassiz for a time espoused this theory, and it was also more or less distinctly held by other writers. The glacier, in fact, was considered to be a magazine of cold, capable of freezing all water percolating through it. The theory was abandoned when this notion of glacier cold was proved to be incorrect.

295. In 1760, Altmann and Grüner propounded the view that glaciers moved by sliding over their beds. Nearly forty years subsequently, this notion was revived by De Saussure, and has therefore been called "De Saussure's Theory," or the "Sliding Theory" of glacier motion.

296. There was, however, but little reason to connect the name of De Saussure with this or any other theory of glaciers. Incessantly occupied in observations of another kind, this celebrated man devoted very little time or thought to the question of glacier motion. What he has written upon the subject reads less like the elaboration of a theory than the expression of an opinion.

§ 50.

Plastic Theory.

297. By none of these writers is the property of viscosity or plasticity ascribed to glacier ice; the appearances of many glaciers are, however, so suggestive of this idea that we may be sure it would have found more frequent expression, were it not in such apparent contradiction with our every-day experience of ice.

298. Still the idea found its advocates. In a little book, published in 1773, and entitled 'Picturesque Journey to the Glaciers of Savoy,' Bordier of Geneva wrote thus:—"It is now time to look at all these objects with the eyes of reason; to study, in the first place, the position and the progression of glaciers, and to seek the solution of their principal phenomena. At the first aspect of the ice-mountains an observation presents itself, which appears sufficient to explain all. It is that the entire mass of ice is connected, and presses from above downwards after the manner of fluids. Let us then regard the collection of ice, not as a mass entirely rigid and immobile, but as a heap of coagulated matter, or as softened wax, flexible and ductile to a certain point." * Here probably for the first time the quality of plasticity is ascribed to the ice of glaciers.

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* I am indebted to my distinguished friend Prof. Studer of Berne for directing my attention to Bordier's book, and to my friends at the British Museum for the great trouble they have taken to find it for me.

299. Bordier was succeeded by a man of far greater scientific grasp and insight than himself. This was Rendu, a Catholic priest and canon when he wrote, and afterwards Bishop of Annecy. In 1841 he laid before the Royal Academy of Sciences of Savoy his 'Theory of the Glaciers of Savoy,' and his communication is printed in the tenth volume of the 'Memoirs of the Academy.'

300. Rendu seized the idea of glacier plasticity with great power and clearness, and followed it resolutely to its consequences. It is not known that he had ever seen the work of Bordier; probably not, as he never mentions it. Let me quote for you some of Rendu's expressions, which fail however to give an adequate idea of his work:—"Between the Mer de Glace and a river there is a resemblance so complete that it is impossible to find in the glacier a circumstance which does not exist in the river. In currents of water the motion is not uniform either throughout their width or throughout their depth. The friction of the bottom and of the sides, with the action of local hindrances, causes the motion to vary, and only towards the middle of the surface do we obtain the full motion."

301. This reads like a prediction of what has since been established by measurement. Looking at the glacier of Mont Dolent, which resembles a sheaf in form, wide at both ends and narrow in the middle, and reflecting that the upper wide part had become narrow, and the narrow middle part again wide, Rendu observes:—"There is a multitude of facts which seem to necessitate the belief that glacier ice enjoys a kind of ductility which enables it to mould itself to its locality, to thin out, to swell, and to contract as if it were a soft paste."

302. To fully test his conclusions, Rendu required the accurate measurement of glacier motion. Had he added to his other endowments the practical skill of a land-surveyor he would be now regarded as the prince of glacialists. As it was he was obliged to be content with imperfect measurements. In one of his excursions he examined the guides regarding the successive positions of a vast rock which he found upon the ice close to the side of the glacier. The mean of five years gave him a motion for this block of 40 feet a year.

303. Another block, the transport of which he subsequently measured more accurately, gave him a velocity of 400 feet a year. Note his explanation of this discrepancy:—"The enormous difference of these two observations arises from the fact that one block stood near the centre of the glacier, which moves most rapidly, while the other stood near the side where the ice is held back by friction." So clear and definite were Rendu's ideas of the plastic motion of glaciers, that had the question of curvature occurred to him, I entertain no doubt that he would have enunciated beforehand the shifting of the point of maximum motion from side to side across the axis of the glacier.

304. It is right that you should know that scientific men do not always agree in their estimates of the comparative value of facts and ideas; and it is especially right that you should know that your present tutor attaches a very high value to ideas when they spring from the profound and persistent pondering of superior minds, and are not, as is too often the case, thrown out without the warrant of either deep thought or natural capacity. It is because I believe Rendu's labours fulfil this condition that I ascribe to them so high a value. But when you become older and better informed, you may differ from me; and I write these words lest you should too readily accept my opinion of Rendu. Judge me, if you care to do so, when your knowledge is complete. I certainly shall not fear your verdict.

305. But much as I prize the prompting idea, and thoroughly as I believe that often in it the force of genius mainly lies, it would, in my opinion, be an error of omission of the gravest kind, and which, if habitual, would ensure the ultimate decay of natural knowledge, to neglect verifying our ideas, and giving them outward reality and substance when the means of doing so are at hand. In science thought, as far as possible, ought to be wedded to fact.

§ 51.

Viscous Theory.

306. And here the merits of a celebrated glacialist already named, rise conspicuously to view. From the able and earnest advocacy of Professor Forbes, the public knowledge of this doctrine of glacial plasticity is almost wholly derived. He gave the doctrine a more distinctive form, and sought to found upon precise measurements a "Viscous Theory" of glacier motion.

307. I am here obliged to state facts in their historic sequence. Professor Forbes, when he began his investigations, was acquainted with the labours of Rendu. In his earliest work upon the Alps he refers to those labours in terms of flattering recognition. But though as a matter of fact Rendu's ideas were there to prompt him, it may be doubted whether he needed their inspiration. Had Rendu not preceded him, he would probably none the less have grasped the idea of viscosity, executing his measurements and applying his reasoning powers to maintain it. Be that as it may, the appearance of Professor Forbes on the Unteraar glacier in 1841, and on the Mer de Glace in 1842, and his labours then and subsequently, have given him a name never to be forgotten in the scientific history of glaciers.

308. The theory advocated by Prof. Forbes was enunciated by himself in these words:—"A glacier is an imperfect fluid, or viscous body which is urged down slopes of a certain inclination by the natural pressure of its parts." In 1773 Bordier wrote thus:—"As the glaciers always advance upon the plain, and never disappear, it is absolutely essential that new ice perpetually take the place of that which is

melted; it must therefore be pressed forward from above. One can hardly refuse then to accept the astonishing truth that this vast extent of hard and solid ice moves as a single piece downwards." In the passage already quoted he speaks of the ice being pressed as a fluid from above downwards. These constitute, I believe, Bordier's contributions to this subject. The quotations show his sagacity at an early date; but in point of completeness his views are not to be compared with those of Rendu, still less with those of Forbes.

309. I must not omit to state here that though the idea of viscosity has not been espoused by M. Agassiz, his measurements, and maps of measurements, on the Unteraar glacier have been recently and rightly cited as the most clear and conclusive illustrations of the doctrine.

310. But why, with proofs before him more copious and characteristic than those of any other observer, does M. Agassiz hesitate to accept the idea of viscosity, as applied to ice? Doubtless because he believes the notion to be contradicted by our every-day experience of the substance.

311. Take a mass of ice ten or even fifteen cubic feet in volume; draw a saw across it to a depth of half an inch or an inch; and strike a pointed pricker, not thicker than a very small round file, into the groove; the substance will split from top to bottom with a clean crystalline fracture. How is this brittleness to be reconciled with the notion of viscosity?

312. We have, moreover, been upon the glacier and have witnessed the birth of crevasses. We have seen them beginning as narrow cracks suddenly formed, days being required to open them a single inch. In many glaciers fissures may be traced narrow and profound for hundreds of yards through the ice. What does this prove? Did the ice possess even a very small modicum of that power of stretching, which is characteristic of a viscous substance, such crevasses would not be formed.

313. Still it is undoubted that the glacier moves like a viscous body. The centre flows past the sides, the top flows over the bottom, and the motion through a curved valley corresponds to fluid motion. Mr. Mathews, Mr. Froude, and above all Signor Bianconi, have, moreover, recently made experiments on ice which strikingly illustrate the flexibility of the substance. These experiments merit, and will receive, full attention at a future time and in another place.

§ 52.

Regelation Theory.

314. I will now describe to you an attempt that has been made of late years to reconcile the brittleness of ice with its motion in glaciers. It is founded on the observation, made by Mr. Faraday in

1850, that when two pieces of thawing ice are placed together they freeze together at the place of contact.

315. This fact may not surprise you, and I cannot go fully into the reason why it surprised Mr. Faraday and others, or why men of very great distinction in science have differed in their interpretation of the fact. The difficulty is to explain where, or how, in ice already thawing the cold is to be found requisite to freeze the film of water between the two touching surfaces.

316. The word *Regelation* has been invented by Dr. Hooker to express the freezing together of two pieces of thawing ice observed by Faraday.

317. Without entering upon the cause of regelation, you may certainly accept it as a fact. Saw two slabs from a block of ice, and bring their flat surfaces into contact, they immediately freeze together. Two plates of ice, laid one upon the other, with flannel round them overnight, are sometimes so firmly frozen in the morning that they will rather break elsewhere than along their surface of junction. If you enter one of the dripping ice-caves of Switzerland, you have only to press for a moment a slab of ice against the roof of the cave to cause it to freeze there and stick to the roof.

318. Place a number of fragments of ice in a basin of water, and cause them to touch each other; they freeze together where they touch. You can form a chain of such fragments; and then, by taking hold of one end of the chain, you can draw the whole series after it. Chains of icebergs are sometimes formed in this way in the Arctic seas.

319. Consider what follows from these observations. Snow consists of small particles of ice. Now if by pressure we squeeze away the air entangled in snow, and bring the little ice-granules into close contact, they may be expected to freeze together; and if the expulsion of the air be very complete, the squeezed snow may be expected to assume the appearance of compact ice.

320. We arrive at this conclusion by reasoning; let us now test it by experiment, employing a suitable hydraulic press, and a mould to hold the snow. In exact accordance with our expectation we convert by pressure the snow into ice.

321. Place a compact mass of ice in a proper mould, and subject it to pressure. It breaks into pieces: squeeze the pieces forcibly together; they re-unite by regelation, and a compact piece of ice, totally different in shape from the first one, is taken from the press.

322. By means of suitable moulds you may in this way change the shape of ice to any extent, turning out spheres, and cups, and rings, and twisted ropes of the substance; the change of form in these cases being effected through rude fracture and regelation.

323. By applying the pressure carefully, rude fracture may be avoided, and the ice compelled slowly to change its form as if it were a plastic body.

324. Now our first experiment illustrates the conversion of the snows of the higher Alpine regions into ice. A similar experiment was made by M. Schlagintweit prior to the discovery which explains it. The deeper layers of the névé have to bear the weight of all above them, and are thereby converted into more or less perfect ice. And our last experiment illustrates the changes of form observed upon the glacier, where, by the slow and constant application of pressure, the ice gradually moulds itself to the valley, which it fills.

325. In glaciers, however, we have also ample illustrations of rude fracture and regelation. The broken cascades are mended at their bases; and when two branch glaciers lay their sides together, the regelation is so firm that they begin immediately to flow in the trunk glacier as a single stream. The medial moraine gives no indication by its slowness of motion that it is derived from the sluggish ice of the sides of the branch glaciers.

326. The gist of the Regelation Theory is that the ice of glaciers changes its form and preserves its continuity under *pressure* which keeps its particles together. But when subjected to *tension*, sooner than stretch it *breaks*, and behaves no longer as a viscous body.

§ 53.

The Veined Structure of Glacier Ice.

327. This power of yielding to pressure produces another effect of the highest interest; but to understand it we must first know something of what is called slaty cleavage.

328. Go to the slate quarries of Bangor and Cumberland, and observe the quarrymen in their sheds splitting the rocks. With a sharp point struck skilfully into the edge of the slate, they cause it to divide into thin plates, fit for roofing or ciphering, as the case may be. The surfaces along which the rock cleaves are called its *planes of cleavage.*

329. All through the quarry you will notice the direction of these planes to be perfectly constant. How is this laminated structure to be accounted for?

330. You might be disposed to consider that cleavage is a case of stratifraction or bedding; for it is true that in various parts of England there are rocks which can be cloven into thin flags along the planes of bedding. But when we examine these slate rocks we verify the observation, first I believe made by the eminent and venerable Professor Sedgwick, that the planes of bedding usually cut across the planes of cleavage.

331. This continued a puzzle to geologists till the late Mr. Daniel Sharpe made the discovery that shells and other fossils and bodies found in slate rocks were invariably flattened out in the planes of cleavage. This observation was ably followed up by Mr. Sorby. You may accept it as proved that slate rocks have suffered great pressure at right angles, or at all events at a high angle to the planes of cleavage.

332. These slate rocks were once a plastic mud, and they may by grinding be converted into their original form. When such mud is carefully squeezed so as to flatten in one direction and spread out in another, it is reconverted into slate. Various other substances, white wax for example, when properly compressed, show a cleavage still more perfect than that of slate.

333. But what bearing have these facts upon the ice of glaciers? This bearing. The ice of the higher regions is whitish through the diffusion of small air bubbles within it. At the sides of the glaciers, and at the bottom of the cascades, this ice is sometimes subjected to enormous pressure. It yields laterally as the slate-mud has yielded, and a laminated structure is the consequence. On the surface of the glacier, under the medial moraines, and on the sides of the crevasses, the lamination reveals itself as clear blue veins or streaks drawn through the whiter ice.

334. This is the *veined structure*, or the *ribboned structure* of glacier ice. It was first described by M. Guyot, but our knowledge of it, and our interest in it, have been mainly derived from the labours of Professor Forbes.

Beyond this my time will not permit me to go. Farewell!

THE END.

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